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A Compact Coastal Ocean Observing System for Kernel Blitz 2001

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Robert A. Weller
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Jeffrey Lord
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December 2001

Technical Report

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Approved for Distribution:

Terrence M. Joyce, Chair

Department of Physical Oceanography

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Abstract

In this report we describe a compact, easily deployed, moored system for oceanographic and meteorological observations in the coastal ocean. The system consists of a surface and subsurface mooring pair deployed adjacent to one another. Compared to a single catenary surface mooring, this arrangement allows the entire water column to be instrumented. All of the instruments in the system log high resolution time series data. Additionally, the mooring line instruments periodically report averaged data to the buoys via inductive modems. On the subsurface mooring, this averaged data is sent to the surface buoy using an acoustic modem. Inductively coupled mooring line instrumentation includes conductivity, temperature, and pressure sensors, acoustic current meters, and optical backscattering and absorption sensors. In addition to mooring line instruments, the surface buoy collects averaged data from meteorological sensors, including wind speed and direction, barometric pressure, relative humidity, air temperature, precipitation, longwave and shortwave radiation, sea surface temperature and conductivity, and wave height and period. Data from both mooring lines and from the surface meteorological sensors is telemetered to shore via line-of-sight radio and satellite. The entire system, including buoys, moorings, instruments, launch and recovery gear, telemetry receive, and data processing facilities can be packed into a single 20 foot shipping container. The system was successfully deployed to provide environmental monitoring for Kernel Blitz 2001, a US Navy fleet exercise off southern California. Results from the deployment are presented.

Contents

1 Platforms, Instrumentation, and Telemetry **7**

1.1 Overview and chronology 7

1.2 Buoy descriptions 11

1.2.1 Surface 11

1.2.2 Subsurface 11

1.3 Description of the instrumentation 13

1.3.1 Temperature, conductivity, and pressure 14

1.3.2 Optical backscattering and attenuation 15

1.3.3 Current 16

1.3.4 Meteorology 16

1.3.4.1 Surface buoy 16

1.3.4.2 *New Horizon* bow mast 18

1.3.5 Wave height and period 18

1.4 Telemetry 19

1.4.1 Satellite and radio 19

1.4.2 Acoustic 20

1.4.3 Inductive 22

1.5 Controllers 23

1.5.1 Electronics 23

1.5.2 Software: Instrument definition 27

1.5.3 Software: Control flow 29

1.5.4 Software: Datafiles 30
1.5.5 Software: Commands 32
1.5.5.1 Deployment control commands 32
1.5.5.2 Instrument control and test commands 33
1.5.5.3 System commands 36

2 Data **39**
2.1 Temperature and salinity 39
2.1.1 Temporal variability 39
2.1.2 Spatial variability 44
2.2 Meteorology 46
2.3 Currents 49
2.4 Optical properties 50

References **53**

List of Figures

1.1 Overview of the environmental observing system deployed for Kernel Blitz 2001. . . 8

1.2 Diagram of the surface mooring. 9

1.3 Diagram of the subsurface mooring. 9

1.4 Map of the Kernel Blitz 2001 exercise area. The mooring site is indicated by the encircled M. 10

1.5 Surface buoy tower prior to recovery. 12

1.6 Instrumented buoy keel and mooring attachment frame. 12

1.7 LOCOMOOR buoy used on the subsurface mooring. 12

1.8 The subsurface pressure case and instrument cage with UAM transducer mounted. . 12

1.9 SBE-37 on mooring wire. 14

1.10 SBE-39 on mooring wire. 14

1.11 a-Beta and SBE-44 clamped on mooring wire. 15

1.12 Argonaut-MD with inductive cable coupler clamped on mooring wire. 16

1.13 Block diagram of the interconnections for the surface and subsurface moorings. Note that some mooring line instruments are not shown. 17

1.14 Bow mast of *RV New Horizon* instrumented with ASIMET modules. 18

1.15 Mooring geometry dictated by the UAM transducer beam pattern. 20

1.16 Surface electronics chassis: TT8V2 controller, FreeWave radio, and UAM 24

1.17 Surface electronics chassis: SIM, accelerometer, and Orbcomm unit. 24

1.18 Electrical schematic and layout of the TT8v2 surface controller interface board. . . 25

1.19 Subsurface electronics chassis: TT8V2 controller and SIM. 26

1.20 Subsurface electronics chassis: UAM. 26

1.21 Electrical schematic and layout of the TT8 subsurface controller interface board. . 27

1.22 Electrical schematic and layout of the TT8 bow mast controller interface board. . . 28

2.1 January–February, March–April, and May–June temperature and salinity profiles at CalCOFI station 90.28 (33.48°N, 117.77°W averaged over 1985–2001. 40

2.2 Temperature and salinity profiles from the CTD casts taken during deployment and recovery operations at the mooring site. 40

2.3 Temperature and salinity profiles from the mooring line SBE-37 and SBE-39 instruments at the beginning and end of the deployment period. 41

2.4 Contours of temperature from the ASIMET SBE-37, seven mooring line SBE-37s, and thirteen SBE-39 instruments. 41

2.5 Contours of salinity from the seven SBE-37 instruments on the surface and subsurface moorings. 41

2.6 Contours of temperature along an offshore section of CTD stations taken by navy ships during Kernel Blitz 2001. 42

2.7 Contours of salinity along the same section as in figure 2.6. 42

2.8 Kernel Blitz 2001 CTD stations. 42

2.9 CalCOFI line 93 CTD stations. 42

2.10 Contours of temperature along CalCOFI line 93 for February and March during the period 1985–2000. 43

2.11 Contours of salinity along CalCOFI line 93 for February and March during the period 1985–2000. 43

2.12 Unfiltered time-series of salinity from the seven mooring line SBE-37 instruments. 43

2.13 Integrated spectral energy above 48 CPD in the salinity data from the mooring line SBE-37s. 44

2.14 Contours of vertical density gradient computed using mooring line SBE-37 data. . 44

2.15 AVHRR sea surface temperature acquired at the CoastWatch West Regional Node on 13 March 2001 at 04:29 local. 45

2.16 Alongshore temperature from CTD stations taken by navy ships during Kernel Blitz 2001. 45

2.17 Alongshore salinity from the same section as in figure 2.16. 45

2.18 Hourly averaged relative humidity and air temperature from the ASIMET HRH module; sea surface temperature from the ASIMET SBE-37. 47

2.19 Hourly averaged barometric pressure and alongshore and cross-shore wind velocity, computed using a coastline orientation of 60° west of north. Alongshore wind is positive upcoast; cross-shore wind is positive oncoast. 47

2.20 Hourly averaged wind speed (from the ASIMET system) and significant wave height from the tri-axial accelerometer on the surface buoy. 48

2.21 Hourly averaged shortwave and longwave radiation from the ASIMET SWR and LWR modules. Net incoming heatflux calculated using TOGA COARE formulae . 48

2.22 PWP modeled SST using hourly averaged air–sea fluxes and initialized by the pre-deployment CTD cast taken at the mooring site. The dashed lines show the linear trend in the observed and modeled time series. 49

2.23 PWP modeled temperature contours. 49

2.24 Hourly averaged cross-shore, alongshore, and up currents at 6 m, 23 m, and 51 m depths. Alongshore currents are positive upcoast, cross-shore currents are positive oncoast. 50

2.25 Visibility at the three a-Beta instruments using the $2/K$ formulation. Hourly K_L values were computed from the single ten second average raw transmission value returned via telemetry. 51

2.26 Near surface a-Beta and surface SeaWiFS visibility. The shaded grey area represents the ±20% error bars on the a-Beta value. Data for the SeaWiFS visibility was extracted by digitizing the bitmapped image available on the NRL website cited in the text. 51

List of Tables

1.1 Shipboard, surface, and subsurface instrument details. Shipboard and surface buoy instrument ids are RS-485 addresses. Surface and subsurface mooring instrument ids are inductive modem addresses. 13

2.1 Alongshore and cross-shore coherent length scales (km) for cross-shore (u) and alongshore (v) currents and temperature (T) from moored current meter arrays deployed between Del Mar and San Clemente, CA in 1980 and 1983 [2, 4]. Summer observations are from the 1980 experiment; spring and winter from the 1983 experiment. There were no cross-shore sites in 1980. Table reproduced from Lentz [2], Table 6. 46

Part 1

Platforms, Instrumentation, and Telemetry

1.1 Overview and chronology

As part of Kernel Blitz 2001/MIREM-16, a US Navy fleet exercise off Southern California, the Upper Ocean Processes (UOP) Group of Woods Hole Oceanographic Institution deployed two moorings and shipboard instrumentation to provide environmental measurements. This effort was a follow-up to an effort by UOP in support of GOMEX-99-2/MIREM-9 off Corpus Christi, Texas in September 1999. That effort involved a shipboard meteorological system and one surface mooring with water column temperature, salinity, and current instruments. There was no real-time telemetry of data. Based on feedback from Navy operators following that exercise and internal UOP development objectives, the idea behind the Kernel Blitz effort was to deploy a significantly enhanced system, including real-time telemetry, optical measurements, increased instrument density, and measurements over the full water column. An overview of the system designed to provide these enhancements is shown in figure 1.1.

The observing system deployed for Kernel Blitz 2001 consisted of a surface and subsurface mooring pair deployed side-by-side. This arrangement allows the entire water column to be instrumented with simple, easy to deploy mooring configurations. The surface mooring was a catenary configuration with instruments down to about 40 m in 55 m water depth. The subsurface mooring was a taut moor, 25 m long, with instruments over the bottom 15 m. Mooring diagrams are shown in figures 1.2 and 1.3.

Instruments on the moorings included conductivity, temperature, and pressure sensors, single bin acoustic current meters, and optical backscattering and absorption sensors. All instruments were internally recording. Additionally, many of the mooring line instruments periodically reported

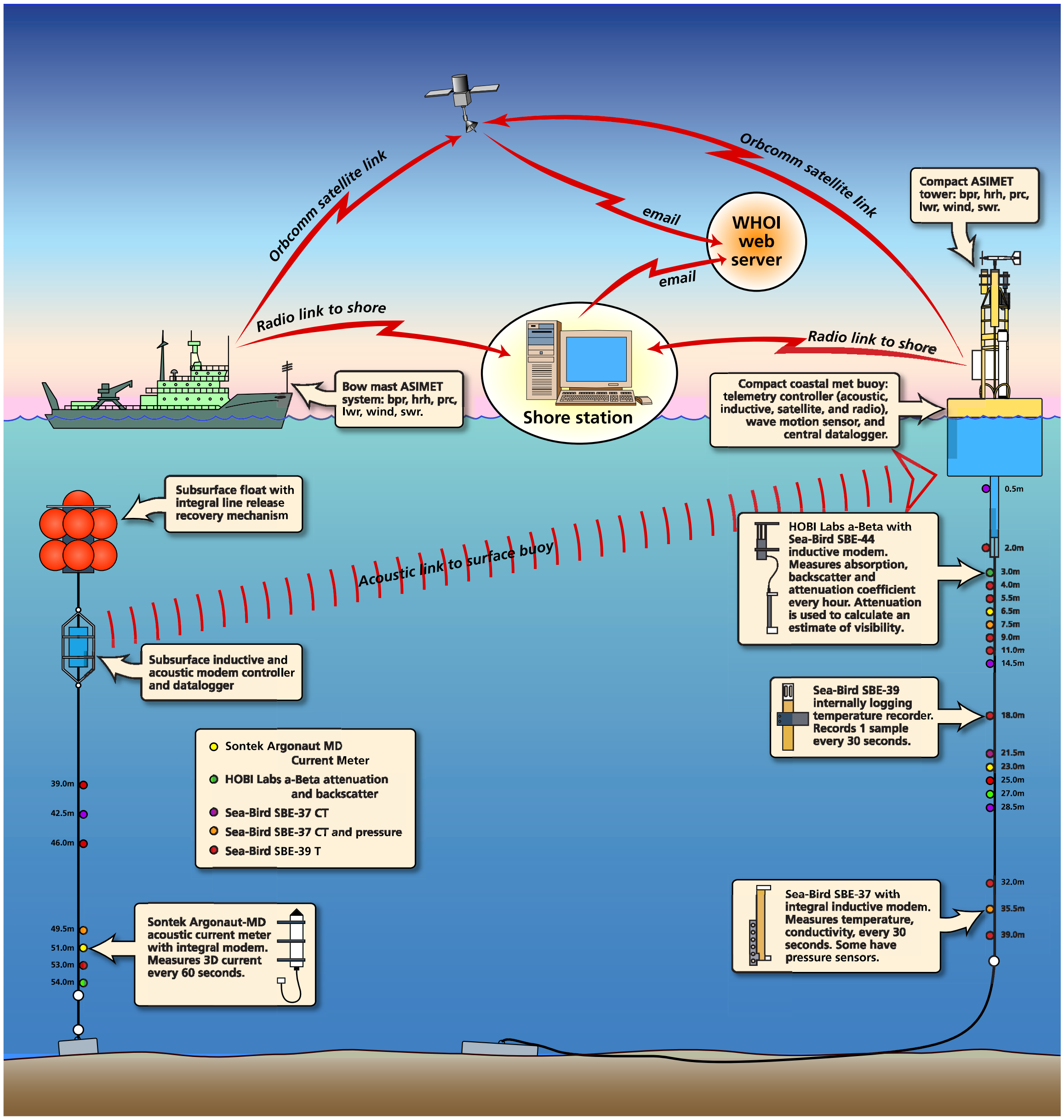

Figure 1.1: Overview of the environmental observing system deployed for Kernel Blitz 2001.

averaged data to the buoys via inductive modems. On the subsurface mooring, this averaged data was sent to the surface buoy using an acoustic modem.

Meteorological instrumentation on the surface buoy included global positioning system (GPS) position, wind speed and direction, barometric pressure, relative humidity, air temperature, precipitation, longwave and shortwave radiation, sea surface temperature and conductivity, and wave height and period. Hourly averaged values from these instruments, along with the averaged data

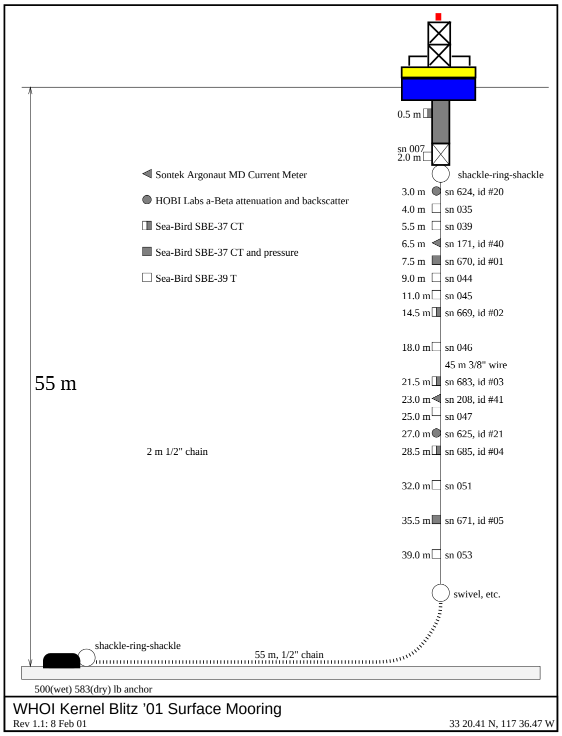

Figure 1.2: Diagram of the surface mooring.

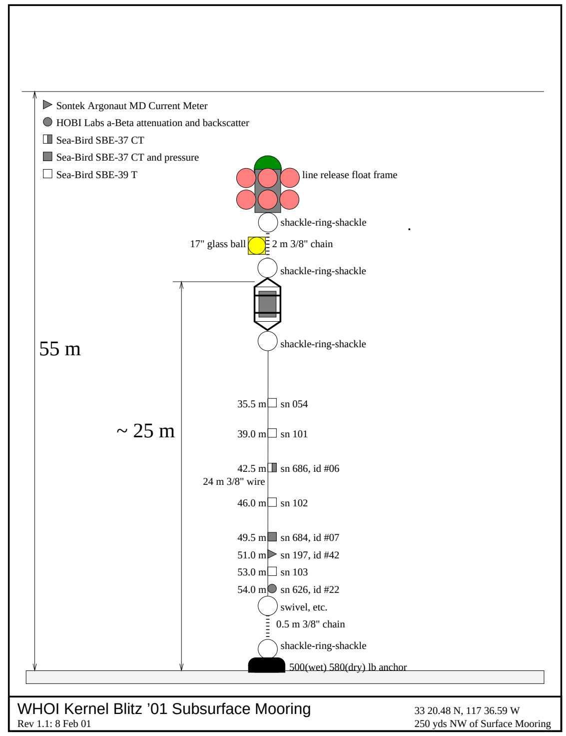

Figure 1.3: Diagram of the subsurface mooring.

from the mooring line instrumentation, were telemetered to shore via line-of-sight radio. A similar telemetry system and meteorological suite (minus the precipitation sensor) was installed on the bow mast of *RV New Horizon* which was operating in the area throughout the Kernel Blitz 2001 exercise.

The location of the moorings is shown in figure 1.4. The surface mooring was deployed at 33°20.41′ N, 117°36.47′ W; the subsurface mooring was deployed at 33°20.48′ N, 116°36.59′ W (250 yds NW of the surface mooring). Water depth at both sites was 55 m. The moorings were deployed on 11 March 2001 and recovered on 30 March 2001. Both operations were conducted from *RV New Horizon.*

The original experimental plan called for both line-of-sight radio and satellite telemetry of the data from the shipboard and buoy based systems. Due to uncertainties regarding the state of the satellite service provider at the time of deployment the decision was made to use only the radio. Prior to leaving the dock on 11 March 2001 both radio systems were running well. Around the time that the ship's engines were started, however, radio contact with both systems was lost. Immediately following deployment of the surface buoy one data packet was received from the surface buoy.

On 12 March 2001 the main receive station was installed at the US Army Reserve Center at the southern end of Camp Pendleton Marine Corps Base, approximately 24 km downcoast from the mooring site. A radio repeater was installed on the ACU-5 (Assault Craft Unit 5) control tower

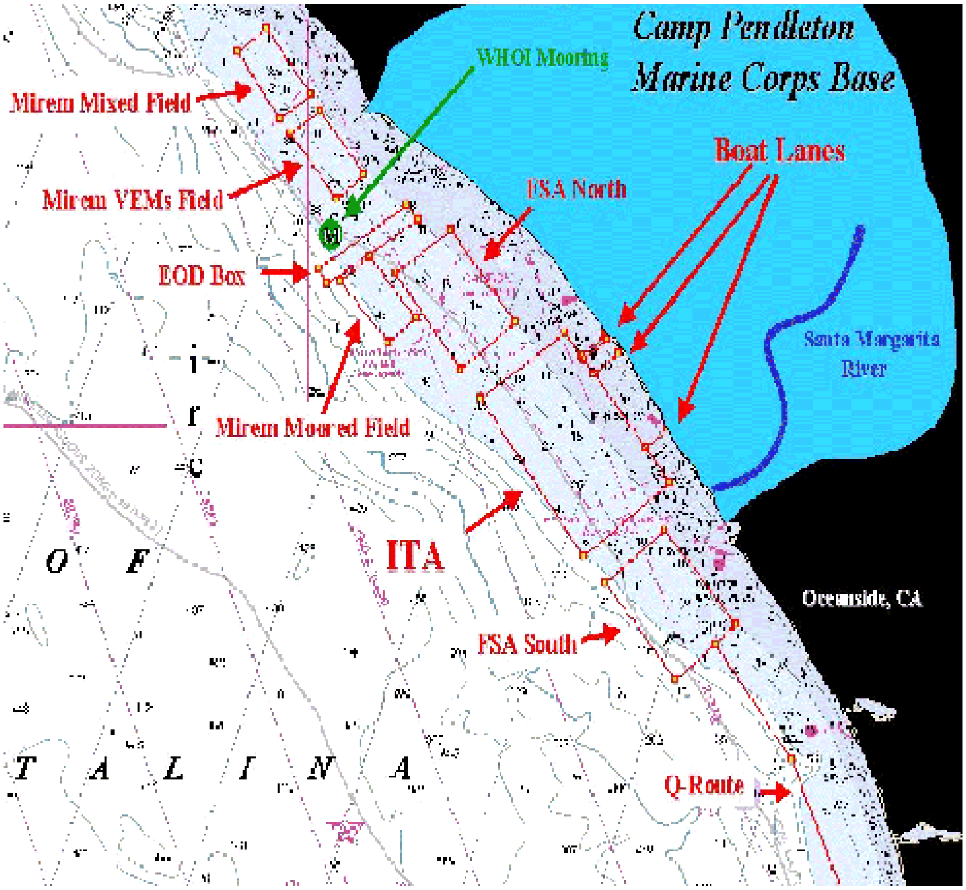

Figure 1.4: Map of the Kernel Blitz 2001 exercise area. The mooring site is indicated by the encircled M.

approximately 17 km downcoast from the mooring site. No data was received throughout the day on 12 March nor was anything received from a mobile station established in the late afternoon on a high bluff 6 km from the mooring site.

The surface buoy was visited via small boat on the morning of 13 March. Through a direct console connection with the surface buoy controller it was determined that all systems were operating as expected. The radio link to a mobile receiver on the boat worked well. Based on this information a second repeater was established on a buoy moored approximately 200 m south of the surface mooring. The antenna on this repeater buoy had more height and was not obstructed by any tower or mast structure compared to the surface buoy. The new repeater was installed very close to the original moorings to minimize problems due to its status as an unplanned, unbroadcast hazard to navigation. The initial repeater buoy simply contained a battery connected directly to a radio so that it was always on and repeating. In this configuration it had a battery life of approximately five days. On 17 March the initial repeater buoy was swapped out for a unit that included a controller to power switch the radio on a 50% duty cycle (on around the expected time of transmission from the surface buoy) and a capacity doubled battery.

Following this improvisation the radio link back to the main receive station did operate successfully. Throughout the experiment there were periods when no data was received, likely due to environmental conditions (haze) and possibly blockage or interference caused by ships. Of the 452 hourly data sets transmitted after the surface buoy was deployed on 11 March, 301 (67%) were received at least partially, and 221 (49%) were received completely. After recovery it was possible to analyze the success rates of the inductive and acoustic links as well. The inductive telemetry from all instruments on both moorings performed with 100% success. Of 449 data sets transmitted acoustically from the subsurface buoy to the surface buoy, 416 (93%) were successfully received.

1.2 Buoy descriptions

1.2.1 Surface

The surface buoy was a modified NOPP (internal WHOI designation) hull with a 1.07 m diameter, 0.63 m high surlyn foam hull with a 2 m long, 0.15 m diameter through pipe for a well. The tower on top of the buoy was a standard NOPP tower with the radar reflector mast replaced by a highly customized, very compact suite of ASIMET (Air Sea Interaction - Meteorology) instruments (figure 1.5). A second light bay was added to provide room for connectors. The mooring attachment frame that connects the buoy tube to the mooring was lengthened and strengthened to provide room to mount the acoustic modem hydrophone, as well as modified to have an integral clevis style attachment point for a chain/wire mooring. The instrumented buoy keel (tube and attachment frame) is shown in figure 1.6. Lead ballast (approximately 135 kg) was added to the keel tube so that the buoy would be stable floating upright with no mooring attached. The lead was mounted on threaded rod which screwed into the clamps normally used for zinc anodes.

1.2.2 Subsurface

The subsurface buoy was a LOCOMOOR (internal WHOI designation) buoy consisting of an EdgeTech Pop-Up Recovery System with AM200 acoustic release and a WHOI designed frame to hold eight additional plastic spheres (figure 1.7). This arrangement provided a net buoyancy of 620 N. To reduce mooring tilt in strong currents a 17-inch glass sphere was added to the chain immediately below the subsurface buoy to provide additional flotation.

The controller and modems for the subsurface mooring were housed in a pressure case that was clamped into an inline cage beneath the subsurface buoy. The cage design was based on the standard 0.25 m square WHOI VMCM (Vector Measuring Current Meter) cage, shortened to an

Figure 1.5: Surface buoy tower prior to recovery.

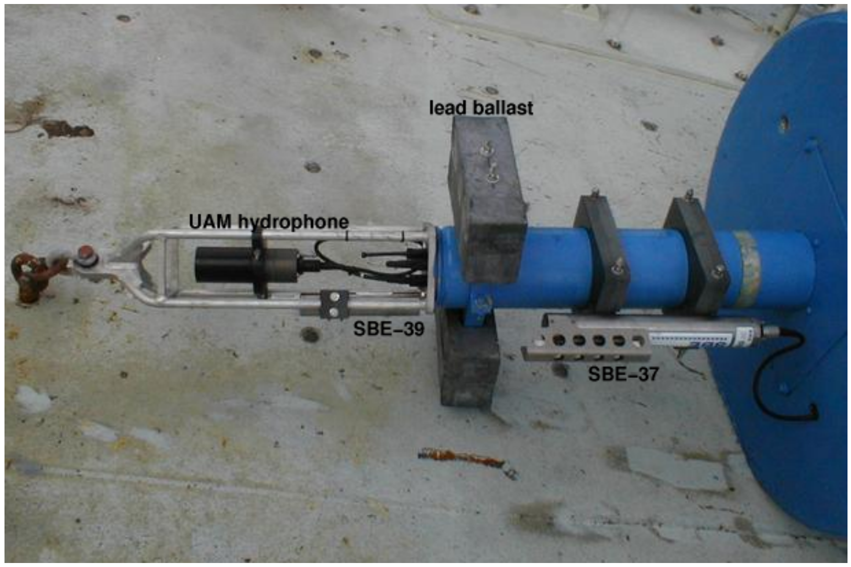

Figure 1.6: Instrumented buoy keel and mooring attachment frame.

Figure 1.7: LOCOMOOR buoy used on the subsurface mooring.

Figure 1.8: The subsurface pressure case and instrument cage with UAM transducer mounted.

overall length of 1.27 m and constructed of 3/8-inch titanium rod rather than 3/4-inch stainless. The cage and clamps alone have a mass of 6.8 kg and a wet weight of 51 N. With endcaps, the PVC pressure case is 0.64 m long, 0.19 m outside diameter and has a mass (with no electronics or batteries) of 7.7 kg. The cage and case are shown in figure 1.8.

	instrument	id	depth	variables	sampling scheme
Surface Buoy	HRH501	01		T_a, RH	BDL logs every 60 s, most recent sample used for hourly telemetry
	PRC501	01		precip	BDL logs every 60 s, most recent sample used for hourly telemetry
	LWR501	01		Q_{lw}	BDL logs every 60 s, most recent sample used for hourly telemetry
	SWR501	01		Q_{sw}	BDL logs every 60 s, most recent sample used for hourly telemetry
	WND343	01		W_e, W_n	BDL logs every 60 s, most recent sample used for hourly telemetry
	BDL L11			BP	logged every 60 s, most recent sample used for hourly telemetry
	SI34103A 0380A00747	01		H_s, T_p	8192 samples at 10 Hz sampled hourly to compute wave spectrum
	KX-G7101 9ABDE207206			lat, lon	hourly GPS fix
	SBE-37SM 1419	01	0.5	T, C	BDL logs every 60 s, most recent sample used for telemetry
	SBE-39 0007		1	T	internally logs every 30 s
Surface Mooring	SBE-37IM 670	01	7	T, C, P	internally logs every 30 s, hourly average for telemetry
	SBE-37IM 669	02	14	T, C	internally logs every 30 s, hourly average for telemetry
	SBE-37IM 683	03	21	T, C	internally logs every 30 s, hourly average for telemetry
	SBE-37IM 685	04	28	T, C	internally logs every 30 s, hourly average for telemetry
	SBE-37IM 671	05	35	T, C, P	internally logs every 30 s, hourly average for telemetry
	SBE-39 0035		4	T	internally logs every 30 s
	SBE-39 0039		6	T	internally logs every 30 s
	SBE-39 0044		9	T	internally logs every 30 s
	SBE-39 0045		11	T	internally logs every 30 s
	SBE-39 0046		18	T	internally logs every 30 s
	SBE-39 0047		25	T	internally logs every 30 s
	SBE-39 0051		32	T	internally logs every 30 s
	SBE-39 0053		39	T	internally logs every 30 s
	Argonaut D171	40	6	V_e, V_n, V_u, T	logs 60 s avgs of 1 Hz pings, hourly avg of 1 minute data for telemetry
	Argonaut D208	41	23	V_e, V_n, V_u, T	logs 60 s avgs of 1 Hz pings, hourly avg of 1 minute data for telemetry
	a-Beta 624/		3	a, K_L, β, P	10 samples in hourly 100 s burst, hourly telemetry gets last sample of burst
	SBE-44 18	20			
	a-Beta 625/		27	a, K_L, β, P	10 samples in hourly 100 s burst, hourly telemetry gets last sample of burst
	SBE-44 19	21			
Subsurface mooring	SBE-37IM 686	06	42	T, C	internally logs every 30 s, hourly average used for telemetry
	SBE-37IM 684	07	49	T, C, P	internally logs every 30 s, hourly average used for telemetry
	SBE-39 0054		35	T	internally logs every 30 s
	SBE-39 0101		39	T	internally logs every 30 s
	SBE-39 0102		46	T	internally logs every 30 s
	SBE-39 0103		53	T	internally logs every 30 s
	Argonaut D197	42	51	V_e, V_n, V_u, T	logs 60 s avgs of 1 Hz pings, hourly avg of 1 minute data for telemetry
	a-Beta 626/		54	a, K_L, β, P	10 samples in hourly 100 s burst, hourly telemetry gets last sample of burst
	SBE-44 20	22			
New Horizon	BPR204	02		BP	internally logs every 60 s, most recent sample for 5 minute telemetry
	WND207	02		W_e, W_n	internally logs every 60 s, most recent sample for 5 minute telemetry
	SWR211	02		Q_{sw}	internally logs every 60 s, most recent sample for 5 minute telemetry
	LWR213	02		Q_{lw}	internally logs every 60 s, most recent sample for 5 minute telemetry
	HRH213	02		T_a, RH	internally logs every 60 s, most recent sample for 5 minute telemetry
	KX-G7101 9ABDE206993			lat, lon	GPS fix every 5 minutes

Table 1.1: Shipboard, surface, and subsurface instrument details. Shipboard and surface buoy instrument ids are RS-485 addresses. Surface and subsurface mooring instrument ids are inductive modem addresses.

1.3 Description of the instrumentation

A summary table of details for all instruments is provided in table 1.1. Additional details about power, sampling scheme, and mechanical mounting are provided below. Details about system interconnections and bulkhead connector details for both surface and subsurface moorings are provided on the block diagram in figure 1.13.

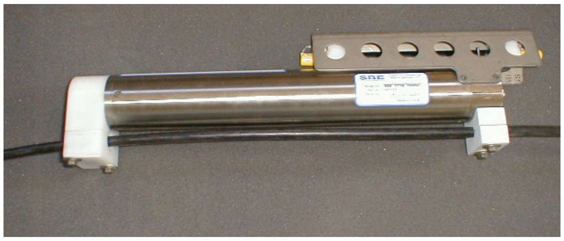

Figure 1.9: SBE-37 on mooring wire.

Figure 1.10: SBE-39 on mooring wire.

1.3.1 Temperature, conductivity, and pressure

Mooring line temperature, conductivity, and pressure instruments were SBE-37 (T, C, and sometimes P) and SBE-39 (T only) instruments manufactured by Sea-Bird Electronics. The seven SBE-37 instruments on the mooring lines (5 surface, 2 subsurface) had integral inductive modems and reported hourly averaged data to the buoys. Three of these instruments (sn 670 and 671 on the surface and sn 684 on the subsurface) had pressure sensors with a full scale range of 100 psia.

The SBE-37 mounted on the buoy keel was part of the ASIMET meteorological system; it communicated with the IMET datalogger via RS-485 and did not internally log. The thirteen SBE-39 instruments (9 surface, 4 subsurface) internally logged temperature only. The sample interval for internally logged data on all SBE-37 and -39 instruments was 30 seconds.

Mooring line SBE-37s derived power from standard Sea-Bird internal lithium battery packs. SBE-39s were powered by internal 9-volt alkaline batteries. The ASIMET SBE-37 was powered through the ASIMET logger/controller, which in turn was powered by buoy primary batteries.

Mooring line SBE-37s were clamped to the mooring wire using the integral clamps as shown in figure 1.9. Mooring line SBE39s were clamped to the mooring wire using a PVC clamping block as shown in figure 1.10. On the keel the SBE-37 was attached using a PVC clamp around the keel tube. The SBE-39 was clamped to the mooring attachment frame using a clamp similar to that used for mooring line SBE-39s. The positions of the keel mounted instruments are shown in figure 1.6.

All inductive (mooring line) SBE-37s returned 100% of data, telemetered and internally recorded. All conductivity data from the IMET SBE-37 on the buoy keel was anomalously high relative to other instruments. An evaluation and post-calibration by Sea-Bird revealed that a failure of analog components in the instrument introduced a bias. These data should be discarded. The pressure data from SBE-37 671 is bad until after 20 March. All SBE-39s except for sn 103 at the bottom of the subsurface mooring returned 100% of data. The record for instrument 103 stops short, at approximately 1800 UTC on 26 March, possibly due to a battery undervoltage.

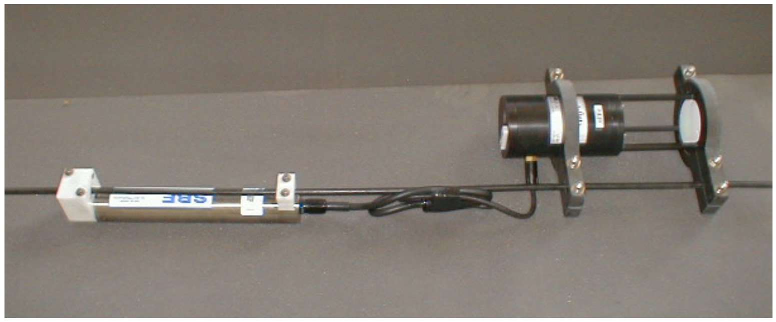

Figure 1.11: a-Beta and SBE-44 clamped on mooring wire.

1.3.2 Optical backscattering and attenuation

The optical instruments on the surface and subsurface moorings were a-Betas manufactured by HOBI Labs. For inductive communications they were paired with Sea-Bird SBE-44 Underwater Inductive Modems (UIMs). Figure 1.11 shows an a-Beta with PVC clamps and SBE-44 with integral inductive clamps on mooring wire. The two instruments communicate over the connecting cable via RS-232. The UIM provides translation between this RS-232 link and inductive communications coming down from the buoy inductive modem controllers.

Prior to deployment, the firmware in all three a-Betas was upgraded from v1.39 to v1.40 in RAM (not Flash so the change was not permanent). This upgrade fixed a bug that caused the a-Betas to occasionally hang and quit responding after a hibernation period. The firmware upgrade was also modified so that rather than the normal wake sequence (Enter key, Enter key, sampling immediately starts) the sequence Enter key, d key would print the most recently sampled line of data and immediately return the instrument to its regular sleep schedule. This change allowed the system controller to query the a-Beta for data without waking the a-Beta fully, allowing for more independent operations between the two.

The a-Betas were deployed beta-side down (a-side up). The body of each instrument was wrapped in electrical tape and the tape was painted with anti-fouling paint. Anti-fouling face plates were installed on the ends with the beta optics. No fouling was evident post-recovery.

The instruments were programmed to sample in burst mode: 10 samples over 100 seconds, hourly on the half-hour. Sampling was done on the half-hour to ensure that they would be asleep when the controller queried them (via the SBE-44) with the modified waking sequence described above. The UIMs and a-Betas each had their own internal power source. SBE-44s used standard Sea-Bird lithium packs. a-Betas have internal rechargeable NiCd batteries.

a-Beta sn 625 did not internally log any data. This is likely due to an error in the instrument setup. The pressure sensor on a-Beta 624 started returning bad values after 25 March. The reason for this failure has not been determined.

Figure 1.12: Argonaut-MD with inductive cable coupler clamped on mooring wire.

1.3.3 Current

Current measurements were made at three depths with Sontek Argonaut-MD single bin acoustic doppler current meters with integral inductive modems. The Argonauts were clamped to the wire with PVC clamps as shown in figure 1.12. Inductive connections were made with inductive cable couplers (ICC) that plug directly into the bulkhead communications connector. The compasses on the Argonaut are configured such that the instruments were deployed down looking. When sampling they ping continuously at 1 Hz. One minute averages of the earth referenced velocities from these pings were logged internally. When queried inductively for data the instruments responded with an average of this one minute data. Power was provided by standard Sontek alkaline D cell battery packs.

All three Argonauts returned 100% of data, telemetered and internally recorded. On instrument 208 the dates returned in the responses to the controller's queries stopped changing after 0604 UTC on 25 March. This error does not appear in the internally recorded data and it does not appear to have affected the actual data returned in the query responses.

1.3.4 Meteorology

1.3.4.1 Surface buoy

The surface buoy ASIMET system was a customized unit designed to fit on the standard NOPP buoy tower. As shown in figure 1.5 the housing for the WND (wind) module forms the central mast on top of the buoy tower. This housing also contained electronics for the HRH (relative humidity and air temperature) and PRC (precipitation) modules. The HRH sensor was mounted with its radiation shield upside down as one of three instruments clamped around the top of the central housing. Other instruments at the top of the mast are LWR (longwave radiation) and SWR (shortwave radiation) modules, both in their most compact (no batteries, front-end electronics only) configuration. The PRC module was bolted to the side of the buoy tower. The sea surface temperature and conductivity

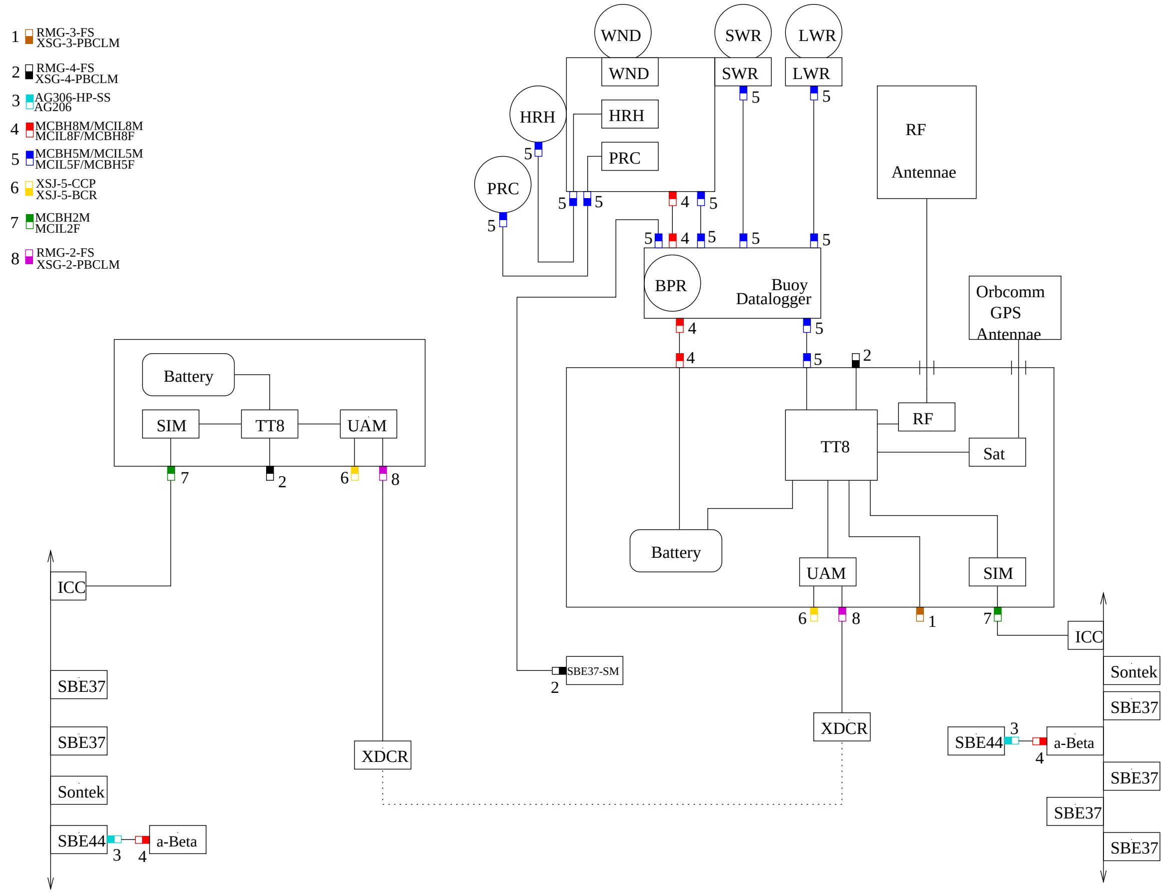

Figure 1.13: Block diagram of the interconnections for the surface and subsurface moorings. Note that some mooring line instruments are not shown.

module (SCT) was the Sea-Bird SBE-37 with RS-485 interface described in section 1.3.1.

All of the modules were controlled and logged by the Buoy Datalogger (BDL) bolted to the buoy tower opposite the PRC module. The BDL also contains an integral BPR (barometric pressure) module. Power to the BDL and hence to the modules is provided by the buoy primary batteries. None of the modules logged data internally. The one minute record for all modules was logged by the BDL. Power and signal connections between modules, BDL, and buoy controller are shown in figure 1.13.

The datalogger returned 100% of data for all modules, both telemetered and internally recorded. With the exception of the failure of analog components on the SBE-37 (resulting in bad conductivity data) noted above all modules appear to have performed well.

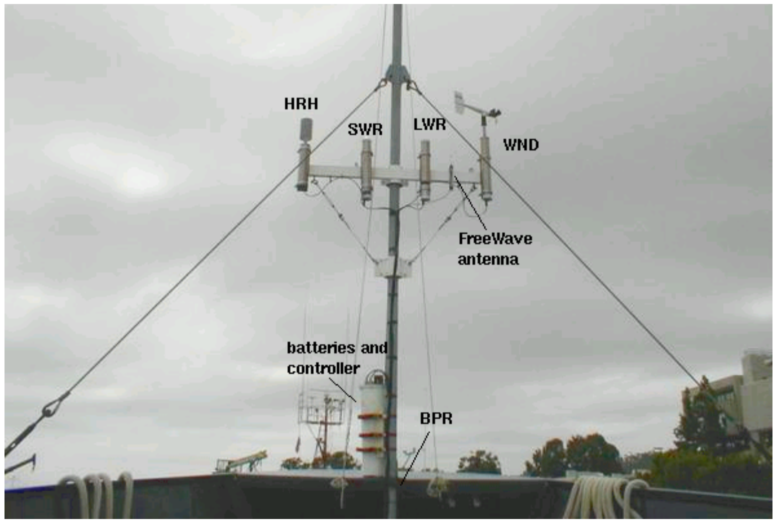

Figure 1.14: Bow mast of *RV New Horizon* instrumented with ASIMET modules.

1.3.4.2 *New Horizon* bow mast

The shipboard ASIMET instruments were mounted to a length of aluminum channel using standard suitcase clamps. The channel was then clamped to the bow mast of the *RV New Horizon.* The BPR barometric pressure module was secured on the deck below the forepeak. The controller and battery housing was ratchet strapped to the base of the bow mast. A photograph of the instrumented mast is shown in figure 1.14.

Shipboard modules internally logged at one minute intervals to internal flash cards. Every five minutes the modules were queried by the controller for their most recent data. This data was used for telemetry and stored on the controller's flash card.

The shipboard controller stopped operating shortly after 1200 UTC on 11 March, just as the ship was leaving the dock. In addition to losing the five minute data that would have been written to flash and any radio telemetry of this data, the failure of the controller resulted in the GPS data being lost. With no record of speed and position, the entire shipboard dataset, and particularly the wind data, are of limited usefulness. Also, the internally logged data record on the wind module was short; no data was recorded after 1400 UTC on 17 March. The reason for this failure has not been determined.

1.3.5 Wave height and period

Wave height and period were calculated hourly from 8192 point time series of tri-axial acceleration from the Summit Instruments SI34103A, sampled at 10 Hz by the controller's onboard 12-bit AD converter. In this process, the surge and sway directions are low-pass filtered in real-time to calculate pitch and roll angles so that the heave acceleration can be rotated into true vertical. The vertical acceleration is then double integrated, with real-time high pass filtering at each step to eliminate drift, into vertical displacement. Once the sampling is complete, the spectrum of this time series of vertical displacement is computed and the peak frequency is determined. The significant height is calculated as $4\sigma_z$ where σ_z is the standard deviation of the time series of vertical displacement.

For Kernel Blitz this processing procedure for the accelerometer data was experimental. Results for significant wave height appear reasonable based on other nearby measurements, but no direct validation data is available. Due to a problem in the software, the calculated peak period values were not correct. This problem has since been corrected.

1.4 Telemetry

1.4.1 Satellite and radio

The shipboard and surface buoy systems were equipped with Orbcomm and line-of-sight radio RF telemetry modems. Orbcomm transceivers were Panasonic KX-G7101 Data Communicators with built-in GPS receiver. The antenna for both systems was an Antenex Dual Band VHF/GPS antenna potted into a PVC cup with a face seal on the bottom so that it mounted right on the endcap. Small leaks were observed with both systems during testing; prior to deployment they were completely sealed with silicone to provide additional waterproofing. As previously stated, due to Orbcomm's possible financial difficulties, satellite telemetry was turned off for Kernel Blitz 2001. The GPS capabilities of the KX-G7101 were still used.

Radio modems were FreeWave Wireless Data Transceivers, model DGR09 on the surface buoy, bow mast, ACU-5 repeater, and repeater buoy, and DGR-115 at the base station. The modems were configured in point-to-multipoint mode: surface buoy and bow mast as point-to-multipoint slaves, repeaters as point-to-multipoint repeaters, and base station as point-to-multipoint master. All of the radios were configured to transmit at their highest power level (1 W, power setting 9). To avoid collisions with other FreeWave networks in the area the frequency key was set to 11 and the network id to 55 on all radios.

The antenna on the surface buoy was a custom made whip manufactured by Webb Research in the same manner as their Argos whip antennas. The base of the antenna has a $\frac{7}{16}$-inch MS fitting which screws directly into a port machined into the endcap. The ship system used a FreeWave 3-dB whip mounted on the bow mast crossbar. The antenna cable came into the electronic housing via a Woodhead bulkhead fitting. The repeater buoy and ACU-5 repeater also used a FreeWave 3-dB whip. The base station antenna was a FreeWave 10-dB YAGI mounted on an ≈ 4 m high pole structure that was placed on top of the highest part of the roof of the US Army Reserve Center at

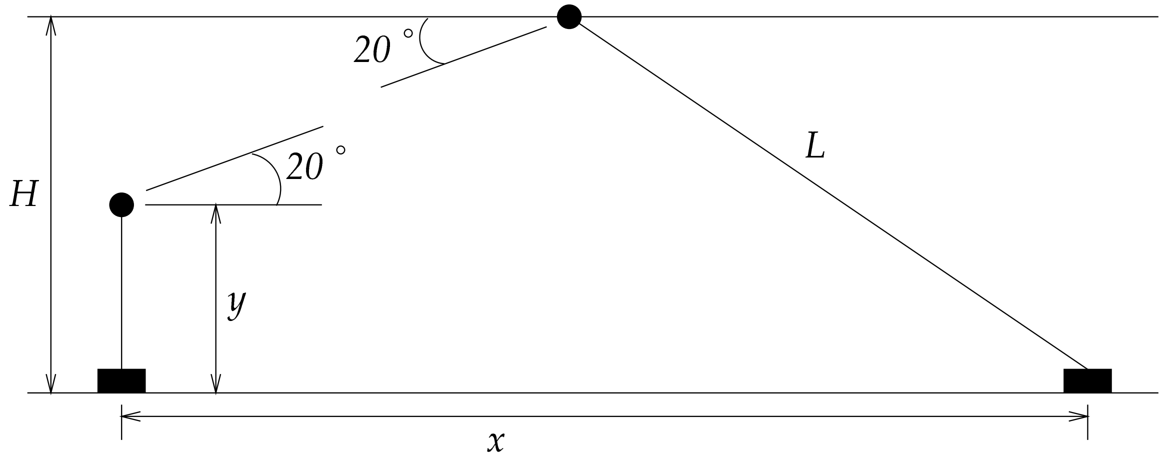

Figure 1.15: Mooring geometry dictated by the UAM transducer beam pattern.

Camp Pendleton.

The radio transmission scheme was very simplistic. Once the data message had been formulated by the controller the radio send data routine on the bow mast or buoy system sent the message in ASCII format 10 times at 30 second intervals. There was no handshaking or error correction between the base station and the slave systems.

1.4.2 Acoustic

The acoustic modems on the surface and subsurface systems were Utility Acoustic Modems (UAMs) version 1.2 designed by the WHOI Acoustic Communications Group. Both systems used three-ring transducers manufactured by Benthos. The mounting configuration for the transducers are shown in figures 1.6 and 1.8.

The beam pattern of the transducers dictated the horizontal separation between the moorings. The transducers radiate acoustic energy in an annulus, $\pm 20°$ off the horizontal. With a horizontal beam the two transducers must be set some minimum distance apart from each other (this contrasts with vertical radiation patterns for which the transducers must be set within some maximum distance from one another). The worst case scenario is diagrammed in figure 1.15. In this case the surface mooring is at its point of closest approach to the subsurface mooring (the situation diagrammed is very conservative: the subsurface mooring is drawn as not responding to the conditions that are pulling the surface mooring so taut). y is the height of the subsurface transducer from the bottom. The surface transducer is assumed to be at the surface, the water depth, H, away from the bottom. L is the total length of the surface mooring and x is the horizontal distance between the two anchors.

For the two transducers to "see" each other, the inequality

$$\frac{H-y}{x-\sqrt{L^2-H^2}} < \tan 20^\circ \tag{1.1}$$

must be satisfied. For example, if the scope of the surface mooring is 2 ($L = 2H$), and the subsurface buoy is at the midpoint in the water column ($y = \frac{1}{2}H$), the separation distance between the anchors, x, must be

$$x > \sqrt{2}H + \frac{H}{2\tan 20^\circ}. \tag{1.2}$$

For Kernel Blitz, $H = 55$ m, $y = 25$ m, and $L = 100$ m, and the requirement was $x > 165$ m. The actual separation of approximately 230 m easily satisfied this.

On the surface system the UAM was treated as an instrument, the data it reported to the controller was simply the complete data message transmitted by the UAM on the subsurface system. The surface system was configured so that the UAM was the last instrument queried for data. The system woke hourly at 45 minutes past hour to begin collecting data. The process of querying all instruments but the UAM typically took about 18 minutes (the majority of which time was spent sampling the accelerometer). The subsurface system woke hourly on the hour and the process of collecting data took approximately one minute. Because the UAMs do not have a remote wake capability the subsurface UAM had to be awake and waiting for an uplink request from the surface to initiate the data transfer. This timing allowed that.

The complete sequence of negotiation and data transfer between the two UAMs is as follows.

1. Once sampling is complete the send data routine for the subsurface (slave) UAM is passed the datafile. It enters into a loop waiting for an uplink request from the surface (master) UAM.

2. When sampling of all other instruments is complete the get data routine for the master sends that uplink request.

3. On receipt of the request the slave UAM passes to the controller three data request messages, one each to fill the three 32-byte frames that make up a packet. In the first of these packets the controller sends the total length of the datafile so the surface knows what to expect.

4. After sending the uplink request the surface controller knows to expect three messages from the master UAM. These messages can be data frames, bad packet, or timeout. If a bad packet message is received the surface controller initiates a reuplink request. This causes the slave UAM to resend the data packet without querying the controller for additional data. If a timeout message is received the controller assumes that the slave UAM never heard the uplink request and it resends that request. This may be a bad assumption – if the slave heard the request and transmitted data but the master never heard anything and thus timed out, a new uplink request will cause the slave to query the subsurface controller for three new frames. This is a serious loss of state and generally results in a completely lost transmission.

5. When the surface controller receives three data frames (a complete packet) it checks to see if the complete datafile has now been received. If it has not, then it sends a new uplink request and steps 3–5 are repeated.

6. Once the complete datafile has been processed by the slave send data routine, the subsurface controller enters a loop waiting for the slave to receive a downlink request.

7. When the complete datafile has been received by the master UAM the surface controller sends that downlink request. This causes the master to pass to the controller requests to fill three data frames. The controller fills these frames with any command information to be processed by the subsurface controller. For the Kernel Blitz configuration that information consisted simply of a message that the slave UAM could be powered down. This operation is simpler than the uplink because there is always only one packet and there is no retry on errors or timeout.

This procedure is far from perfect and is not entirely error free even within the constraints of the current UAM implementations. The process for error retry and handshaking with the slave about when it is alright to shutdown could be improved.

Other problems with the current software interface are related to power and rebooting. The UAMs are wakened by an IO line going high; to put them to sleep the controller must wait for a command request over the serial port and then send a shutdown message. Because a UAM cannot send command requests and listen for messages from the controller while simultaneously listening for acoustic activity, it is desirable from an acoustic detection standpoint to minimize the time spent listening to the serial port. For stability reasons it is also desirable to periodically reboot the UAM. These requirements work against the very fine control of power switching that the controllers try to implement to minimize overall power consumption.

1.4.3 Inductive

On the surface and subsurface moorings, the primary length member was a single length of $\frac{3}{8}$-inch jacketed 3x19 wire rope (jacket diameter $\frac{1}{2}$-inch). Individual shots were avoided to provide a continuous signal path for the inductive link. A Sea-Bird Inductive Cable Coupler (ICC) was clamped to the wire just below the topmost boot. The ICC has a molded-in pigtail which was connected to a 2-pin bulkhead connector on the bottom endcap of the surface buoy or subsurface pressure case. The ICC pigtail ran up the boot, looped loosely around the shackle-ring-shackle assembly, and along the mooring attachment frame or cage, held in place over its length with tape and tie wraps. In this arrangement the inductive signal path is a closed loop formed by the wire and the seawater path between the exposed clevis ends of the wire. The ICC is simply an inductive coil which connects via the pigtail/bulkhead to a transformer on the Sea-Bird SMODEM-1 Surface Inductive Modem (SIM) on the controller system.

For the purposes of the control system, the entire inductive system (SIM plus inductive SBE-37s, inductive Sontek Argonaut-MDs and SBE-44 connected a-Betas) was treated as a single instrument. When queried by the controller for data the SIM control functions would in turn query each of the attached instruments to form the complete inductive data message.

1.5 Controllers

1.5.1 Electronics

The controllers for all three systems (surface, subsurface, shipboard) were Onset Tattletale Model 8 computers mated with Persistor CF8 compact flash storage. The surface buoy used a Tattletale 8v2 and CF8v2; the subsurface buoy and shipboard system had older style units. The only difference in the new units is the elimination of Squishy Bus connectors in favor of a more reliable pin and socket design. The radio repeater buoy deployed on 17 March had an 8v2 controller system (identical to the surface buoy system) installed simply for power switching purposes.

The surface buoy system was responsible for sampling, controlling, and communicating with the UAM (Utility Acoustic Modem), FreeWave radio modem, Panasonic Orbcomm satellite modem and GPS receiver, Sea-Bird Surface Inductive Modem (SIM), ASIMET Buoy Datalogger, and the accelerometer used for wave measurements. The two sides of the buoy electronics chassis are shown in figures 1.16 and 1.17. Figure 1.18 shows the schematic and connector placement for the controller interface card that mates to the TT8v2 to provide connections to the various peripherals. The base interface board is an Onset PR8v2 prototyping board which provides access to all of the Model 8's input and output lines.

Power was provided by three Pro Battery 900241-56 D Cell assemblies, wired in parallel to yield 12 V with a nominal capacity of 294 A-hr. The batteries were stacked at the bottom of the tube and held in place by a battery retaining ring. This battery stack was also used to power the ASIMET system.

With no RF telemetry or accelerometer, the subsurface system consisted of just the controller, SIM, and UAM. The two sides of the subsurface electronics chassis are shown in figures 1.19 and 1.20; the schematic and connector placement for the controller interface card are shown in figure 1.21. Because of the requirement for fewer IO lines, the subsurface interface fit on Onset's smaller IO-8 prototyping board. Power was provided by a single Pro Battery 900189-72 D Cell assembly (13.5 V, 112 A-hr).

The shipboard system consisted of a TT8 controller, Panasonic KX-G7101 Orbcomm/GPS unit, and FreeWave radio. The layout and schematic for the interface board (an IO-8) are shown in figure 1.22. The control and telemetry electronics and batteries were housed in the recycled VAWR Argos housing shown at the bottom of the bow mast in figure 1.14. All of the bow mast ASIMET

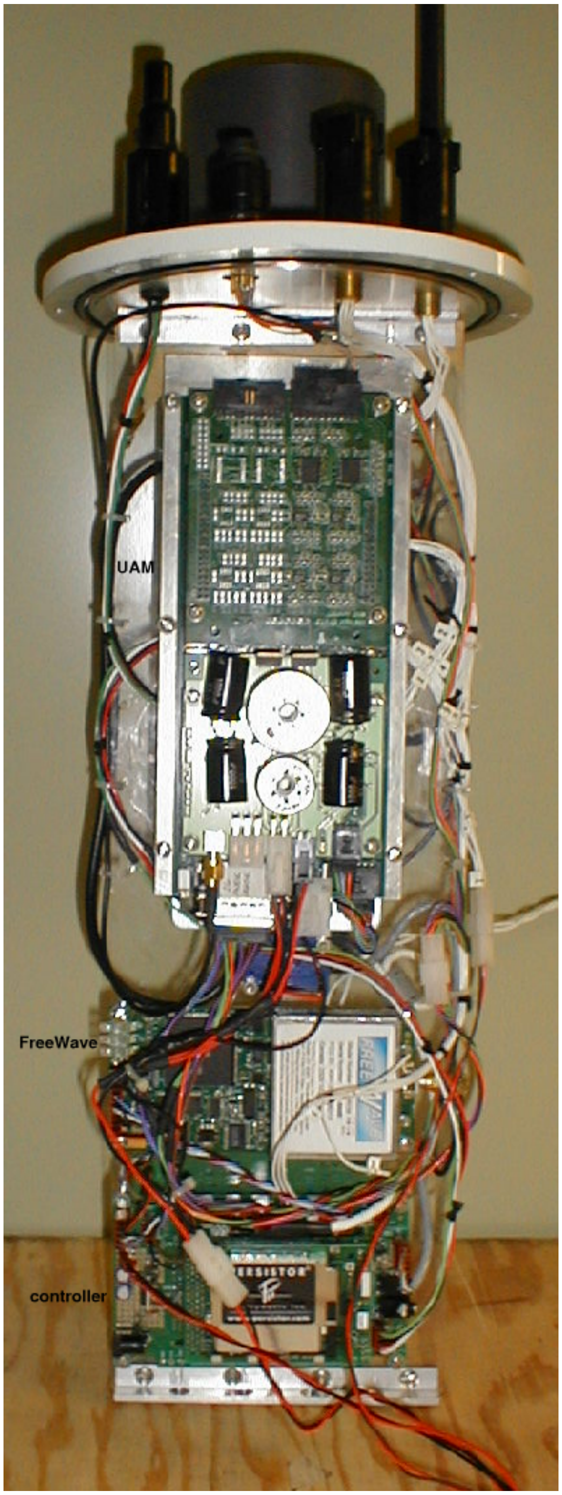

Figure 1.16: Surface electronics chassis: TT8V2 controller, FreeWave radio, and UAM

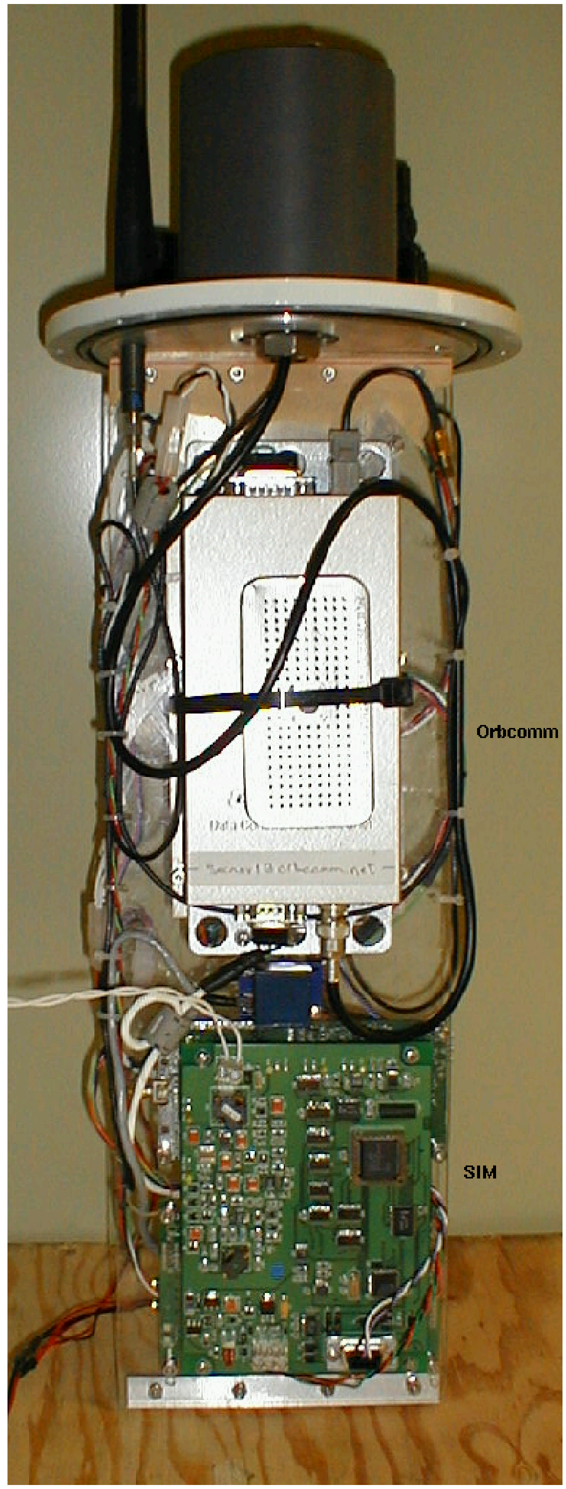

Figure 1.17: Surface electronics chassis: SIM, accelerometer, and Orbcomm unit.

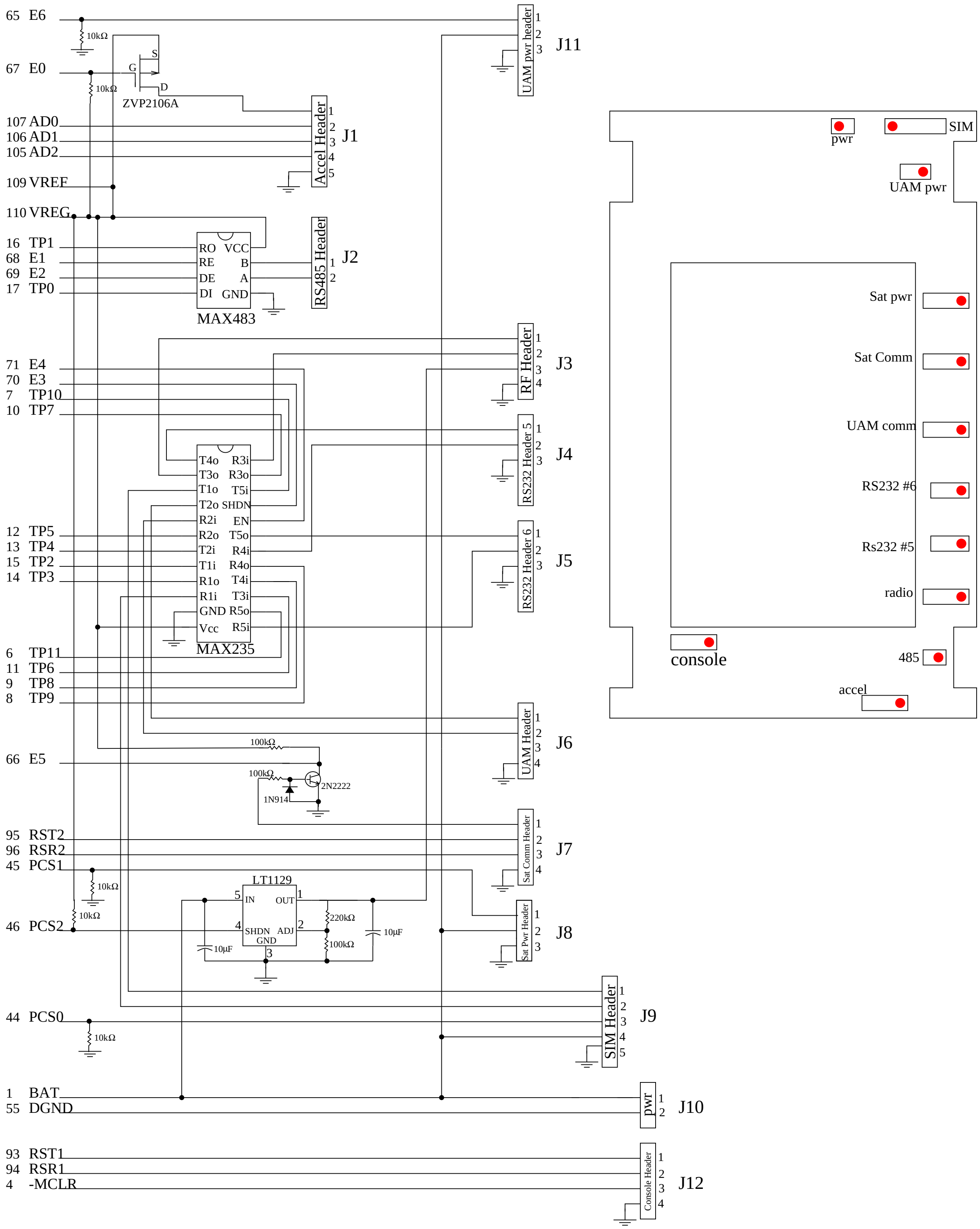

Figure 1.18: Electrical schematic and layout of the TT8v2 surface controller interface board.

Figure 1.19: Subsurface electronics chassis: TT8V2 controller and SIM.

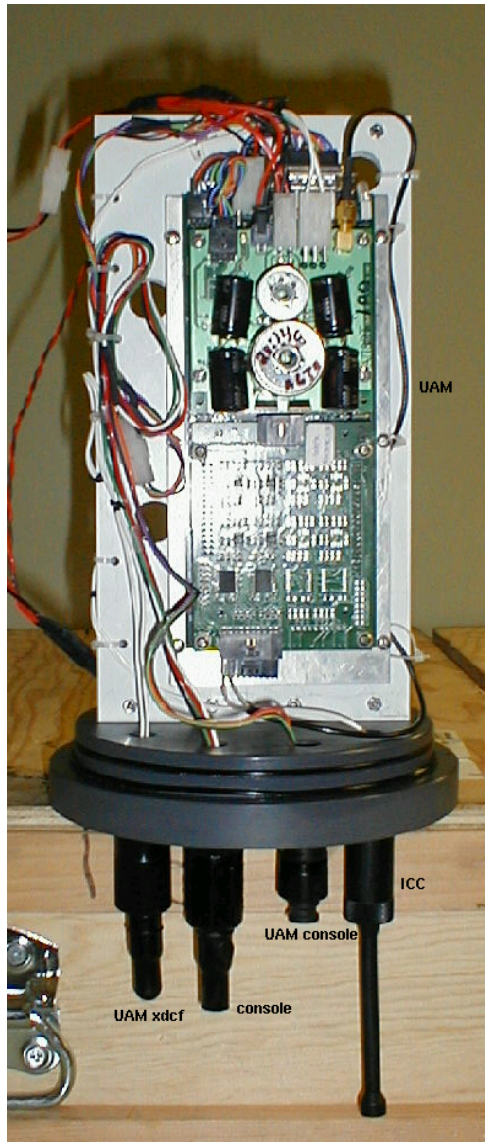

Figure 1.20: Subsurface electronics chassis: UAM.

modules were tied to the single RS-485 bus on the controller in a star configuration. The batteries, two Pro Battery 900189-72 D cell assemblies wired in parallel, powered both the control/telemetry system and the ASIMET modules.

As noted above the shipboard controller failed on 11 March at approximately the time that the ship left the dock. The reason for this failure is unknown, but may have been caused by a bad connection (via the Squishy Bus) between the TT8 and CF8.

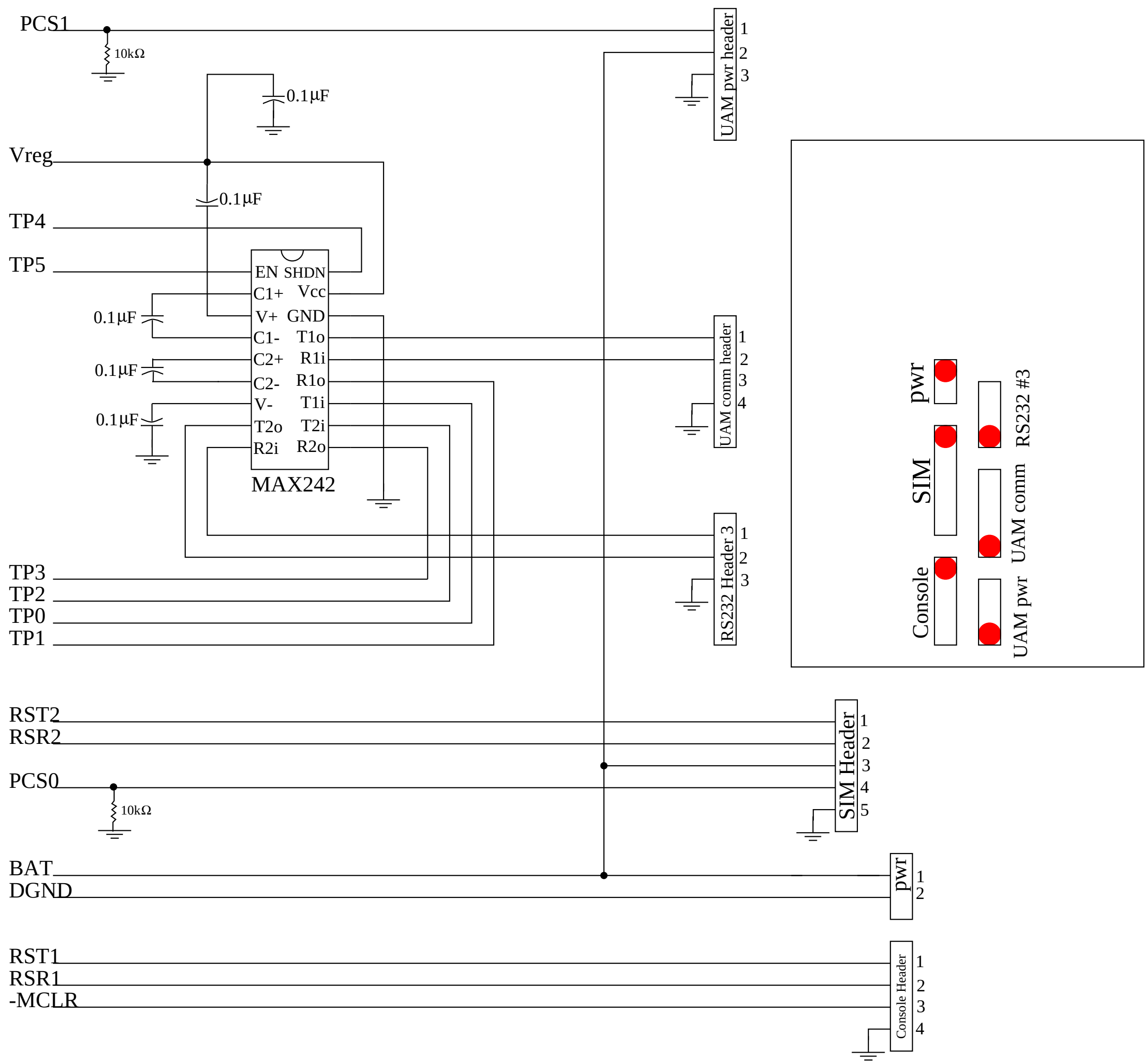

Figure 1.21: Electrical schematic and layout of the TT8 subsurface controller interface board.

1.5.2 Software: Instrument definition

Though there are differences in the wiring and layout of the interface boards for the three controllers they are electronically very similar; from a software standpoint they are nearly identical. From system to system the software only differs in the hardcoded list of installed instruments and telemetry devices and in routines that reference control lines to which those devices are connected.

For each system there is a single source file that contains system specific information. The most important part of this file is an array of instrument definitions. An instrument definition consists of communications port information (TPU lines on the TT8), baud rate, power function, get data

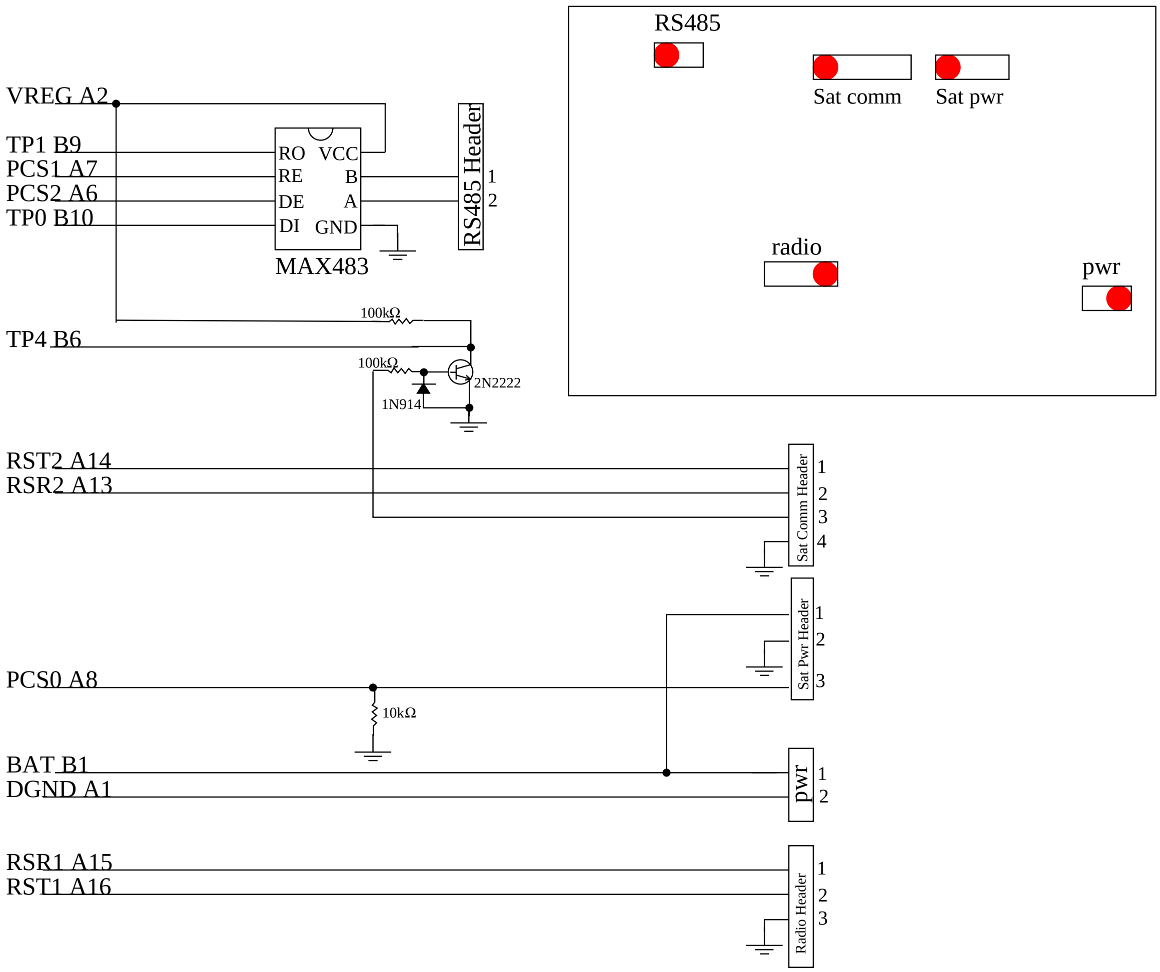

Figure 1.22: Electrical schematic and layout of the TT8 bow mast controller interface board.

function, send data function, auxiliary control function, terminal function, and auxiliary data string. The power function for each instrument is also in this file because they typically access hardware specific IO lines on the TT8. The get data, send data, auxiliary control, and terminal functions are contained in source files specific to each peripheral and are shared among systems.

This definition structure allows an attached device to be defined as a data provider (get data function defined), data sender (send data function defined), or both. The definition for the same type of device may vary from system to system. For example, the UAM on the subsurface system is a data sender, but it is a data provider (i.e., the system gets data from it) on the surface buoy. The Panasonic KX-G7101 Orbcomm unit provides both transmit (via Orbcomm) and data (GPS position) functionality. For ease of control of the system, however, it is easier in this case to treat the two functions as two instruments – one with a send data function defined and one with a get data function defined.

The terminal function in most cases is shared between many instruments. It provides a patch-through for direct communications between the user and peripherals. Devices that require a special sequence to enter into a command or user mode (such as the Orbcomm units) do need a device-specific function. The half-duplex nature of the RS-485 bus also requires that a device-specific function be implemented.

The auxiliary control functions are device-specific routines to test or set parameters on the attached peripherals. Many peripherals require additional system-specific data beyond what is provided in the instrument definition structure to operate. In order to keep this system-specific information out of the code for the peripherals so that the code can be shared among systems, this information is stored in the auxiliary data array. This array is a simple byte array that can be interpreted by the peripheral control code in whatever way is most convenient. For example, the auxiliary data array for the accelerometer is a string containing the number of samples and FFT size to use in calculating wave data. This string is parsed by the accelerometer routines to extract the numeric values. The string can be changed by the auxiliary control function defined in the instrument definition for the accelerometer. The accelerometer auxiliary function also allows the user to put the device into a variety of test modes.

For the inductive modem and RS-485 instrument definitions, the auxiliary array is used to define the addresses of the instruments attached to the signal loop. The auxiliary control function for these instruments allow the user to change these addresses (e.g., if a sensor is removed or added) programmatically, without having to change the installed firmware. Details about the format of the address strings and how to change them are provided in section 1.5.5.2.

1.5.3 Software: Control flow

On powerup the control program calls the power function for each attached peripheral to turn the device off. It then executes any commands in the script file “param.scr” on the compact flash card and any additional script files specified on the command line. If no input was received from the user it enters auto deployment mode according to hard coded default settings and any settings in the script files.

Deployment mode, the primary operating mode of the controllers, is similar to burst mode on many instruments: long periods of low power hibernation interrupted by short periods of sampling activity. In each waking period the controller sequentially powers and calls the get data function for each available attached instrument. When this process is complete the controller sequentially powers and passes the datafile to the send data function of each available telemetry device. The controller then enters low power sleep until the next waking period.

In this mode the operating cycle is governed by the `interval`, `imodulus`, `ioffset` and `telemetry` settings. The `interval` settings determines the number of seconds between the start of consecutive activity periods. For Kernel Blitz the `interval` setting for surface and subsurface systems was 3600 (one hour); for the bow mast system it was 300 (five minutes). The `telemetry` setting determines the number of cycles to collect data before activating the telemetry functions. A setting of 1 indicates that telemetry should be sent at every cycle. This option is intended to reduce the power and cost sometimes associated with a large number of small transmissions. The `imodulus` and `ioffset` settings are used to determine how long to sleep after an auto restart so that the operating cycle will remain on a regular grid. Given a modulus value m and offset value n, on an automatic restart at time t the system will enter low power sleep for

$$m + n - (t \bmod m)$$

seconds. t is the number of seconds since the epoch derived from the controller real-time clock. Once the system wakes from this sleep it will begin cycling using the `interval` setting.

The Tattletale Model 8 does not have a hardware, battery backed real-time clock (RTC). If power is interrupted for more than a few seconds the real-time clock will be cleared (or possibly even filled with garbage) and the sampling that begins after an automatic restart will not return to the original grid. The restart procedure is mainly intended as a failsafe in case of a software bug causing an exception on the controller. In this case the exception handler tries to pass control to PicoDOS. All of the controller flash cards have an autoexec.bat file that points to a RAM version of the control program on the flash card. When PicoDOS restarts, the control program is automatically started.

1.5.4 Software: Datafiles

Two different types of datafiles are created during the instrument sampling process. The get data routine for each instrument may write to an instrument specific datafile with the raw query responses of the instrument(s). The controller provides a convenience routine that returns a base filename based on the deployment start date and time so that all instrument specific files will have similar names. The extension to this filename defines the instrument that created it: acc for accelerometer, imt for RS-485 ASIMET queries, bdl for Buoy Datalogger, sim for Surface Inductive Modem, etc. These are ASCII files with the response from a single instrument per line. The SIM and RS-485 routines prepend the instrument address to the line; the BDL function prepends a timestamp based on the controller RTC.

The second datafile contains the primary data returned from the instrument get data routines in a compact format suitable for telemetry. Each instrument returns an array of 32-bit structures. Each 32-bit structure represents one value that will be added to the datafile and telemetered:

- 5 bits for base instrument type or class, e.g., μCat, accelerometer, IMET. 0 is not used and 1 is reserved for clock or timestamp values. This allows for up to thirty different classes of instrument to fit within this framework.

- 7 bits of instrument id. Disallowing 0, this permits up to 127 instruments of each class to be attached to the system.

- 4 bits for variable type within the class, e.g., temperature, conductivity, and pressure for a μCat, BP, RH, SST, LWR, etc. for an IMET system. 0 is not used. This allows 15 different types of variables to be returned by each instrument class.

- 16 bits for the data value. For each variable type within an instrument class the system must have knowledge of the possible range of raw values that will be returned by the instrument query. Based on this information the data packaging routines scale the raw value into an unsigned short (maximum value 65535) and pack the result into two bytes, LSB first.

Clock values are the exception to these rules. Because there is only one RTC, all 27-bits beyond the 5-bit class are used to store the time: 6 bits for minute, 5 bits for hour, 5 bits for day of month, 4 bits for month, and 7 bits for years past 1900. Clock values mark the start of the instrument query process for all data values that follow until a new clock value is read. They do not represent an exact timestamp for the associated data.

The most recently collected array of 32-bit data entries collected from all instruments is written to the controller flash card after every sampling cycle. Depending on the value of the `telemetry` parameter, it may also be sent through attached telemetry devices or it may be held in a buffer and sent later when the number of sample cycles reaches the value of `telemetry`.

The send data routines for the telemetry peripherals have the option of decoding the packed binary format of the datafile into a human readable ASCII message (this is also the formatted message that the controller displays on the console port). For Kernel Blitz, this option worked well with the high speed, zero cost, loss prone FreeWave transmissions. To conserve bandwidth and increase the likelihood of getting multiple messages through in cases of backlog the Orbcomm units would have transmitted the binary format message.

This representation for the data has the advantage that all information needed to decode the data messages is always present within the message itself. This approach was chosen because it allows the shore side decoder to be written with no knowledge of the exact instrument load on a system and it allows the structure of the message to change arbitrarily throughout the experiment (e.g., if an instrument does not respond during a given query cycle or stops responding altogether). The disadvantage is that there is redundant information from one message to the next in most cases. In future versions it is possible that when the structure of the message does not change in subsequent messages the instrument class, id, and variable type information could be stripped before telemetry. The clock value would be flagged to indicate this stripping and only the 16-bit data values would follow.

1.5.5 Software: Commands

The controller communicates with the host over the console port using RS-232 (9600,N,8,1 protocol). On startup if the user sends `ctrl-c` before the ten second delay has passed automatic deployment will be aborted and a command prompt (the '>' character) will appear. At the prompt the commands described below control the operation and settings of the control system. Note that all command names can be abbreviated to their first two letters and that capitalization of the command does not matter (though capitalization of arguments to the command may).

In the command descriptions the attached instruments are referred to in several different ways. The list of all attached devices is hard coded for each version of the controller. It can be displayed using the `list` command described below. To allow programmatic control over the devices that are actually used, instruments from this list can be made available or unavailable for all modes of access using the `add` and `del` commands. If an instrument is made unavailable it will continue to show up in the `list` output, but it will not be queried for data or used for telemetry in deployment mode, and it cannot be made active for use with any other commands.

The commands that operate on a single instrument all rely on the definition of an active instrument by the `current` command. To be made active an instrument must be available. Making an instrument active always turns its power on. Other instruments may be powered simultaneously. Making another instrument active automatically powers off the previously active instrument. Powering off the active instrument makes no instrument active.

1.5.5.1 Deployment control commands

`clock` *mm/dd/yyyy hh:mm:ss*
: Sets the controller RTC to the given date and time. If no argument is given the current RTC value is displayed.

`start` *mm/dd/yyyy hh:mm:ss*
: Enters deployment mode with the first wake cycle at the date and time specified by `mm/dd/yy hh:mm:ss`. If no date is given then the first sample cycle will begin immediately. Before sampling is started all instruments are powered off and settings for `interval`, `telemetry`, `imodulus`, `ioffset`, `fsys`, the availability of instruments, and any auxiliary data strings that have been changed are written as a command script to the file param.scr on the flash card. This will restore the system configuration in case of auto restart.

`interval` *n*
: Sets the interval in seconds between wake cycles. If no *n* value is given the current setting is displayed.

`telemetry` *n* Sets the number of sample cycles to buffer before activating the send data functions of active telemetry devices. A value of 1 means telemeter the data during every wake cycle. If no value is given the current setting is displayed.

`imodulus` *n* Sets the start interval modulus in seconds for the initial wake cycle following an auto restart (see section 1.5.3). If no value is given the current setting is displayed.

`ioffset` *n* Sets the interval offset in seconds for the initial wake cycle following an auto restart (see section 1.5.3). If no value is given the current setting is displayed.

`save` Saves settings for `interval`, `telemetry`, `imodulus`, `ioffset`, `fsys`, the availability of instruments, and any instrument auxiliary data values that have been changed as a script file named param.scr on the flash card. This command is automatically called when the `start` command is executed.

1.5.5.2 Instrument control and test commands

`gather` Cycles once through the collect data/transmit data for all available instruments. None of the results are written to flash card datafiles. Mainly used for testing.

`list` Lists all of the connected instruments, including whether or not the instrument has get data, send data, and auxiliary functions defined, whether the the instrument is available to be accessed by deployment mode or user commands, whether the instrument is the active instrument, and the power state of the instrument.

`add` *instrum* Makes *instrum* available for access for deployment mode and user commands.

`del` *instrum* Makes *instrum* unavailable for access for deployment mode and user commands, essentially hiding the instrument from the controller until an `add` *instrum* command is issued.

`current` *instrum*

Make *instrum* the active device for `func`, `fetch`, `talk`, and `transmit` commands. If power to *instrument* is off this will turn it on. This will not turn power off to the previously current instrument. When an instrument is current the command prompt will change to '*instrument*>'.

`on` *instrum* Turns power on to *instrum*. If no instrument is active this will make it so.

`off` *instrum* Turns power off for *instrum*. If *instrum* is active or *instrum* is not given this will power down the current active instrument and make no instrument active.

`fetch` Execute the get data routine for the current active instrument and print the results. The instrument must have a get data function defined of course. Nothing is written to flash card datafiles.

`transmit [-f` *`filename`* `| -s` *`string`*`]`
Execute the send data routine for the current active instrument. If the -f option is used the file on the flash card given by *filename* will be transmitted by calling the send data function with sequential 512-byte blocks of the file. If the -s option is used, *string* will be sent in a single transmission.

`talk` *logfile* Enters terminal mode (calls the terminal function) for the current active instrument, providing a direct means of communicating with the device. Sending `ctrl-D` will end the terminal function and return to the command prompt. If a *logfile* name is specified then a diary of the session will be saved to the CF card in *logfile*.

`func` *args* Calls the auxiliary function for the current active instrument with arguments given by *args*. Most auxiliary functions will print a help message or default settings if no arguments are given. Instrument definitions that have auxiliary functions are:

accel
- `func change` *nsamples nfft*
  Changes the number of samples per cycle and the number of points in each windowed FFT used to calculate the spectrum. If *nsamples* and *nfft* are not given the current values will be displayed.
- `func test [g|t] [c|v|G]` *nsamples*
  Display *nsamples* of raw accelerometer output over the console port in [g]raphical or [t]abular format, in units of [c]ounts, [v]olts, or [G]s. Pressing any key on the console will abort the test.

UAM
- `func test`
  On a slave UAM this will call the UAM send function with a 256-byte array filled with values 0 to 255. On a master UAM this will generate an uplink request and put the UAM into a loop to receive this data. The array requires three packets of three frames each to be transmitted. The command should be executed on the slave before it is run on the master.

UWM
- `func cmd value`
  Emulates executing the LinkQuest provided DOS command `cmd` with (for set commands) an argument given by `value`. Most, but not all LinkQuest command programs are emulated. `cmd` can be one of: `set_wp`, `get_wp`, `set_mode`, `get_mode`, `get_ver`,

`set_tadr`, `get_tadr`, `set_oadr`, `get_oadr`, `set_pow`, `get_pow`, `mdm_rst`. See the LinkQuest manual for usage details of the various commands. Note that like the original DOS programs, the actual setting of a parameter within a set procedure is preceded by a modem reset.

SIM

• `func`
Displays the current inductive address string.
• `func change` *address string*
Changes the list of inductive instrument addresses queried by the SIM. *address string* is a character string consisting of addresses concatenated together with no spaces. The inductive address is constructed from a two letter prefix and the two digit inductive id. Valid prefixes are ST (Sontek Argonaut-MD), AB (a-Beta connected to an SBE-44 UIM), MC (SBE-37 μCat CT sensor), and MP (SBE-37 μCat CTP sensor. Example: "MC01MP02ST41AB22".
• `func restore`
Restores the original address string hardcoded in the control program.

imet

• `func`
Displays the current RS-485 bus address string.
• `func change` *address string*
Changes the list of RS-485 addresses queried by the controller. *address string* is a character string consisting of addresses concatenated together with no spaces. The bus address is the same as the ASIMET module address. Example: "WND01LWR01SWR01BPR01".
• `func restore`
Restores the original address string hardcoded in the control program.
• `func dump`
For each module in the bus address string attempts to dump the module data using #*addr*L (to get the number of full records), #*addr*FR and sequential carriage returns to get the data, and X to terminate the process. The output is saved to a file named *addr*.dat on the controller flash card.

bdl

• `func dump`
Attempts to dump the logger flash card using #FS (to get the number of full records), #FR and sequential carriage returns to get the

data, and X to terminate the process. The output is saved to a file named BDLdump.dat on the controller flash card.

orbcomm • `func [clear|no] [burn|no] [wait|no]`
Displays the number of messages currently in the outgoing queue and whether a satellite is currently in view. Optionally clears the outgoing queue. If a satellite and a gateway are in view the gateway ID can be burned into controller EEPROM as the default gateway to use for outgoing messages (not recommended). If no gateway is in view then the function can wait for one to become available, displaying its ID when found, and if desired burning the ID into controller EEPROM as the default.

1.5.5.3 System commands

`sleep` *n* Enters low power sleep mode for *n* seconds. Sending two consecutive ESC values will terminate the sleep prematurely.

`timeout` *n* Sets the console inactivity timeout in seconds. If no value is given the current setting is displayed. A value of 0 disables the inactivity timeout. If the controller does not see any activity on the console serial port in *n* seconds, it will enter an infinitely long low power sleep. To wake the system send two consecutive ESC values.

`echo` *on* | *off* Sets the duplex (local echo mode) for console communications.

`system` *cmd args*
Executes the PicoDOS command given by *cmd* with command-line arguments *args*.

`script` *filename*
Executes all commands in the file given by *filename*. This file must be stored on the controller compact flash card. Script files can consist of any valid list of commands, one per line.

`fsys` *freq* Sets the system clock frequency.

`tom8` Exit to the Tattletale's TOM8 monitor.

`dos` Exit to PicoDOS, the compact flash operating system. Before exiting any autoexec.bat file on the flash card is renamed to autoexec.bak.

`reset` Reboot and restart program (if running from TT8 flash) or PicoDOS (which may have an autoexec.bat file which loads the controller program from flash card into TT8 RAM).

`help` Displays a help message listing all commands with brief descriptions.

Part 2

Data

2.1 Temperature and salinity

2.1.1 Temporal variability

Over the course of the experiment both temperature and salinity profiles steepened. The combination of heating at the surface and cooling at the bottom that contribute to this steepening is an annual phenomenon in this area [5]. Figure 2.1 shows the mean T and S profiles for January–February, March–April, and May–June for the period from 1985–2001 at CalCOFI station 90.28, near the mooring site. The March–April period clearly represents a transition from well mixed winter conditions to more stratified spring and summer conditions.

Consistent with these climatological results, the experimental temperature data show a marked heating at the surface and cooling at the bottom (figures 2.2 and 2.3). Surface salinity remained roughly constant, but there is a marked increase in bottom salinity over the 20 day experiment.

The evolution of the temperature and salinity structure over the course of the experiment are shown in figures 2.4 and 2.5. The slow, persistent intrusion of relatively cold, salty water along the bottom is clear in these figures. One possible explanation for the intruding bottom water is upwelling. Current and (to a lesser degree) wind data are suggestive of upwelling conditions (sections 2.2 and 2.3). That this water may be coming from offshore is also supported by contours of temperature and salinity from CTD casts taken by navy ships during Kernel Blitz 2001. Figures 2.6 and 2.7 show temperature and salinity from the offshore section of CTD casts shown in figure 2.9. This offshore source can also be seen in data from CTD stations along CalCOFI line 93 (figure 2.8) taken during February and March in the period 1985–2000 (figures 2.10 and 2.11).

On shorter time scales the variability is predominantly diurnal (atmospheric forcing) and semi-diurnal (tidally driven). The semi-diurnal variability is evident in the regular spiking at the surface

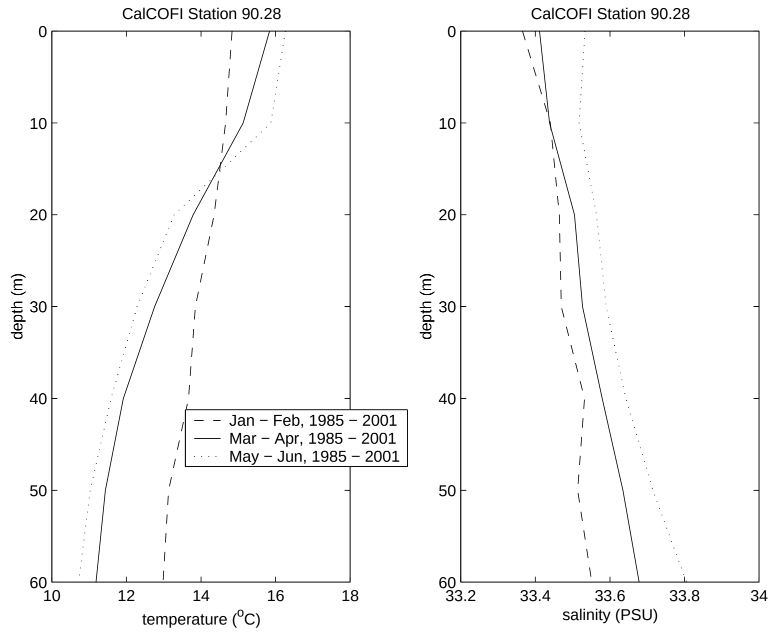

Figure 2.1: January–February, March–April, and May–June temperature and salinity profiles at CalCOFI station 90.28 (33.48°N, 117.77°W averaged over 1985–2001.

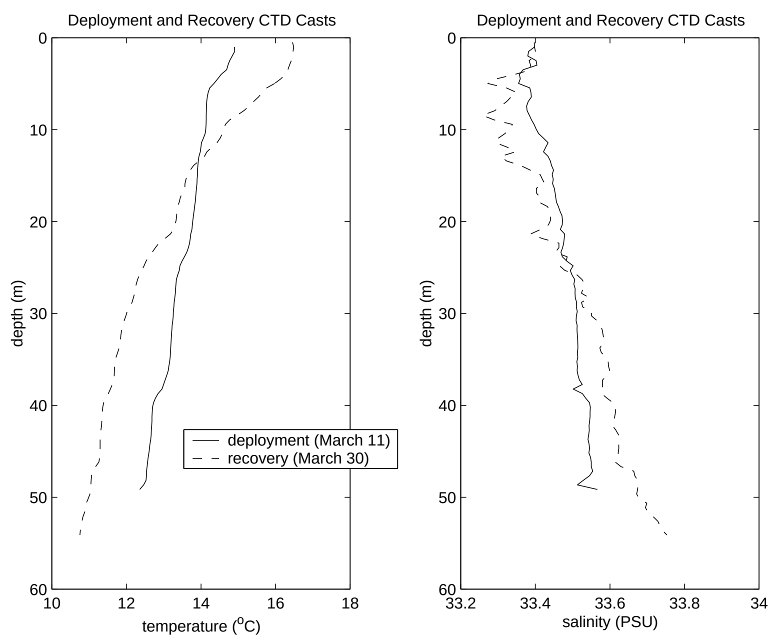

Figure 2.2: Temperature and salinity profiles from the CTD casts taken during deployment and recovery operations at the mooring site.

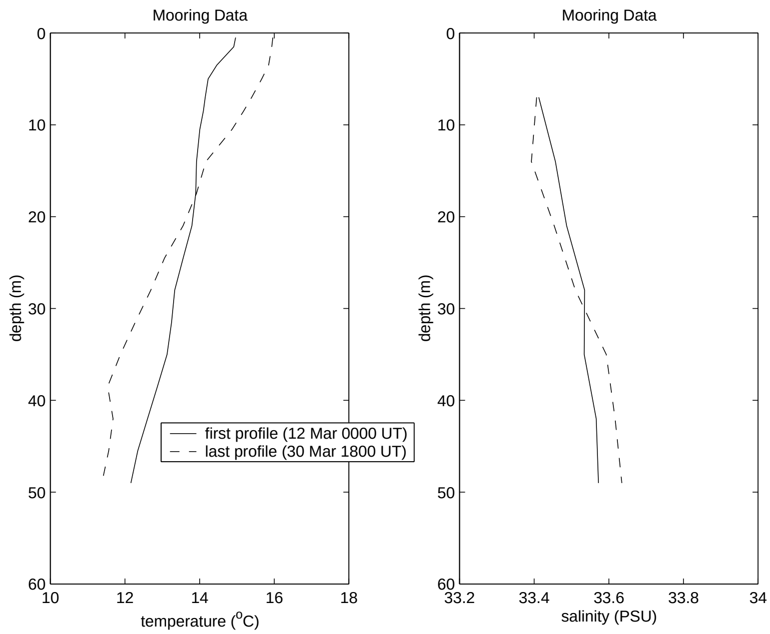

Figure 2.3: Temperature and salinity profiles from the mooring line SBE-37 and SBE-39 instruments at the beginning and end of the deployment period.

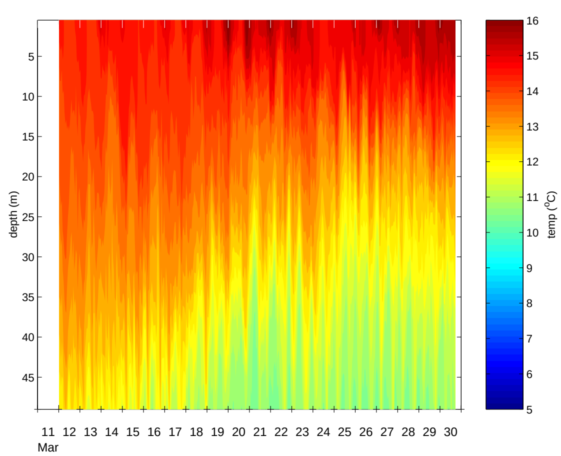

Figure 2.4: Contours of temperature from the ASIMET SBE-37, seven mooring line SBE-37s, and thirteen SBE-39 instruments.

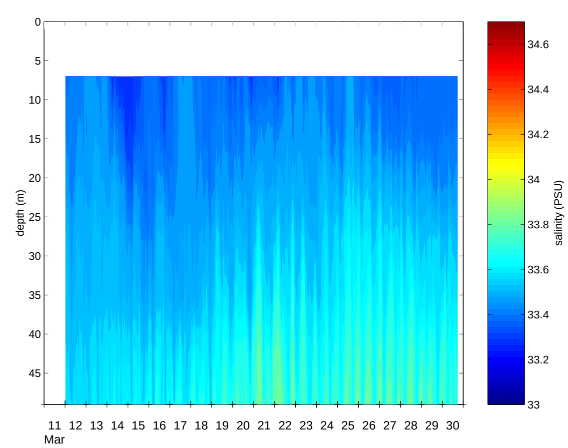

Figure 2.5: Contours of salinity from the seven SBE-37 instruments on the surface and subsurface moorings.

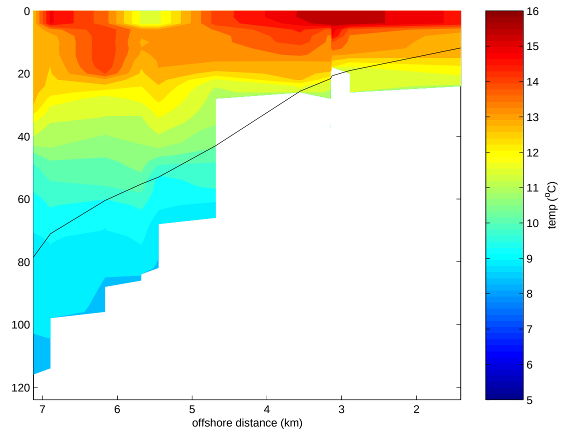

Figure 2.6: Contours of temperature along an offshore section of CTD stations taken by navy ships during Kernel Blitz 2001.

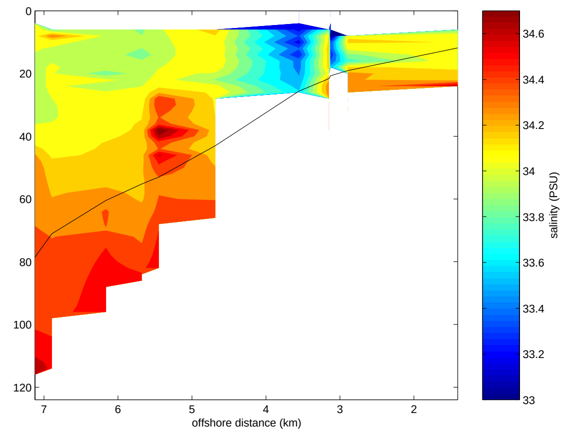

Figure 2.7: Contours of salinity along the same section as in figure 2.6.

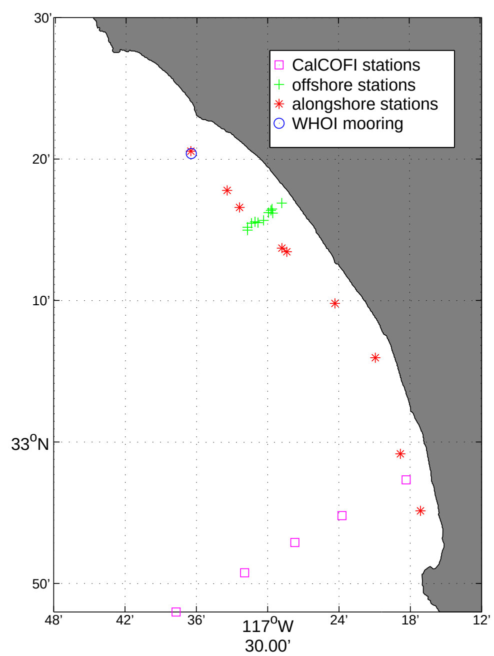

Figure 2.8: Kernel Blitz 2001 CTD stations.

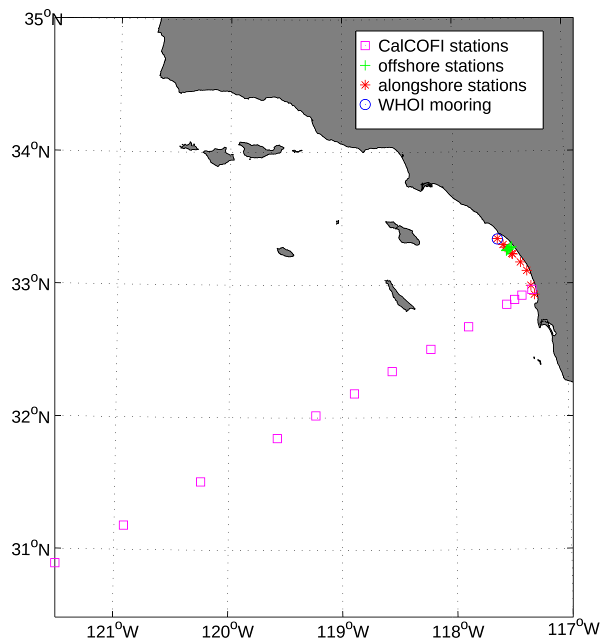

Figure 2.9: CalCOFI line 93 CTD stations.

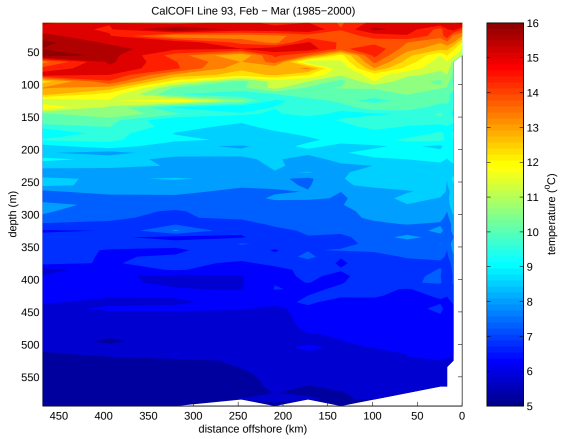

Figure 2.10: Contours of temperature along CalCOFI line 93 for February and March during the period 1985–2000.

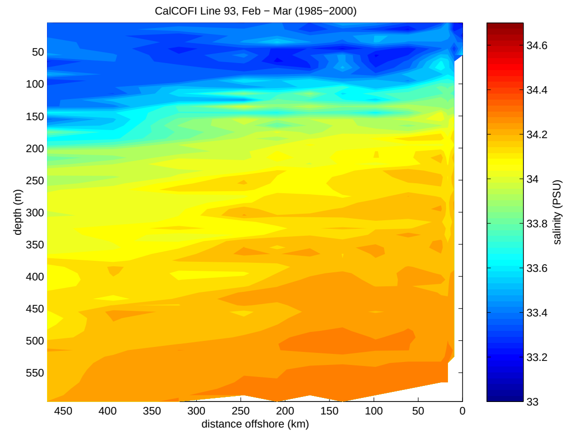

Figure 2.11: Contours of salinity along CalCOFI line 93 for February and March during the period 1985–2000.

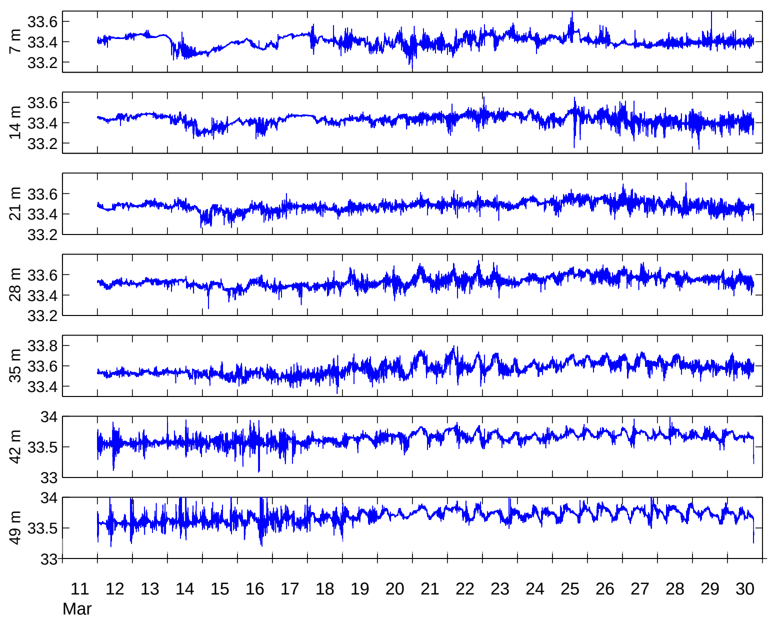

Figure 2.12: Unfiltered time-series of salinity from the seven mooring line SBE-37 instruments.

and bottom in figures 2.4 and 2.5. Atmospherically forced variability is primarily evidenced by the diurnal heating and cooling at the surface in figure 2.4. Some of this variability can be predicted from the surface meteorological measurements (see section 2.2).

Energy at frequencies higher than semi-diurnal appears to be predominantly due to internal waves and is highly depth and time dependent. Figure 2.12 shows the unfiltered (30-second data)

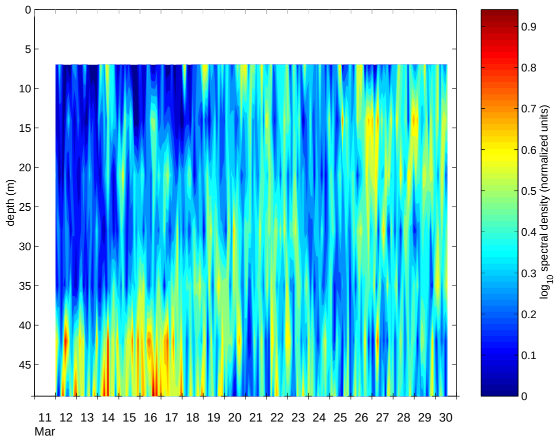

Figure 2.13: Integrated spectral energy above 48 CPD in the salinity data from the mooring line SBE-37s.

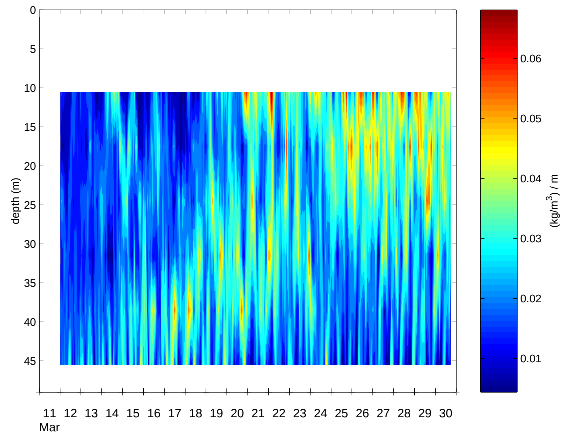

Figure 2.14: Contours of vertical density gradient computed using mooring line SBE-37 data.

time series of salinity from all of the mooring line SBE-37 instruments. There are long bursts of high frequency energy in these signals that appear to move upwards through the water column over the course of the experiment. This energy is tracked quantitatively in figure 2.13 which shows the integrated spectral energy in the salinity signal for frequency content above 48 cycles per day (CPD). The depth–time locations of the high frequency energy correspond well with the maxima in the vertical density gradient (figure 2.14). As cold, salty water intrudes along the bottom, the density interface moves upwards in the water column. Because the internal waves are supported on this interface, the high frequency internal wave energy moves upwards as well.

2.1.2 Spatial variability

Figure 2.15 shows one of the relatively few clear AVHRR images acquired by the CoastWatch West Regional Node (http://cwatchwc.ucsd.edu) during the exercise period. Within the exercise area there is patchy variability of approximately 1°C. This patchiness is also evident in the offshore temperature and salinity sections in figures 2.6 and 2.7 and in alongshore sections also from CTD casts taken by navy ships (figures 2.16 and 2.17). Strong vertical stratification is also evident in both offshore and alongshore directions. Note that these CTD data are not quality controlled and were not taken in any temporally or spatially consistent way. The station locations for the sections are shown in figure 2.8.

Based on a series of previous experiments in this area [2, 4] it is possible to characterize the typical length scales for current and temperature signals. Table 2.1 shows the coherent length scales (defined roughly as the separation over which the signal at two spatial points remains correlated at a level greater than 0.5) in the along- and cross-shore directions for currents and temperature.

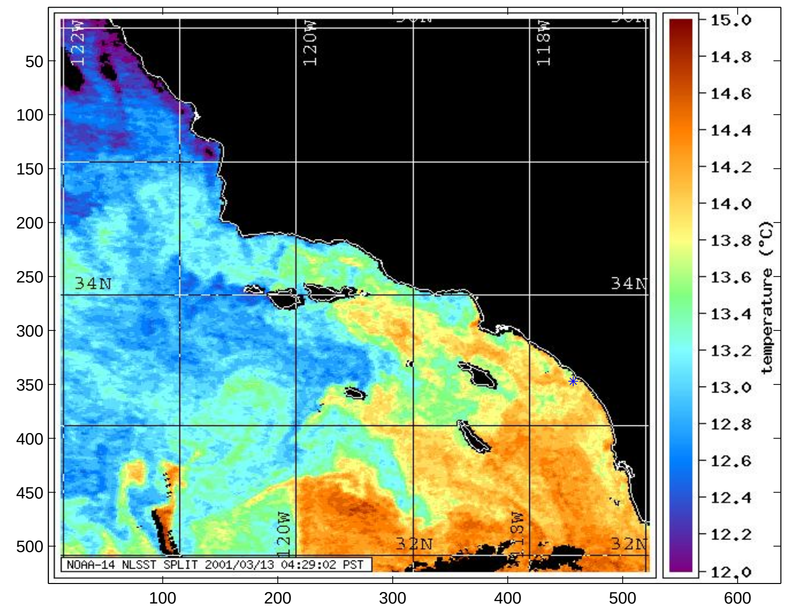

Figure 2.15: AVHRR sea surface temperature acquired at the CoastWatch West Regional Node on 13 March 2001 at 04:29 local.

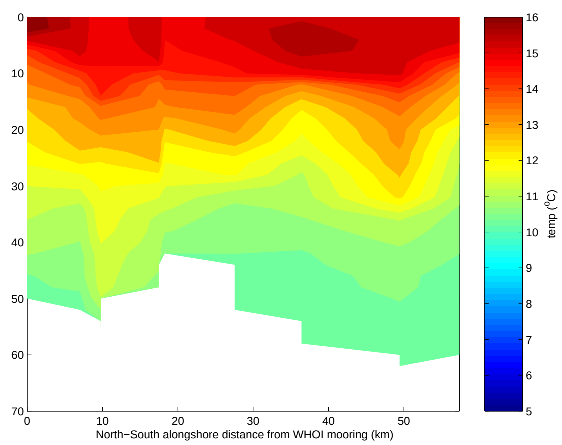

Figure 2.16: Alongshore temperature from CTD stations taken by navy ships during Kernel Blitz 2001.

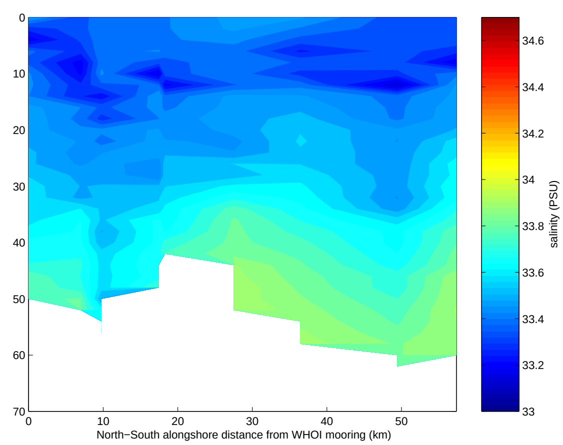

Figure 2.17: Alongshore salinity from the same section as in figure 2.16.

		LF: 0 – 0.6 cpd			IF: 0.6 – 12 cpd		
		u	v	T	u	v	T
along	Winter	< 2.5	25	> 60	5	5	< 2.5
	Spring	< 7	> 50	> 50	< 7	< 7	10
	Summer	< 7	30	> 50	< 7	< 7	10
cross	Winter	3	10	10	3	5	< 2.5
	Spring	3	10	10	3	5	< 2.5

Table 2.1: Alongshore and cross-shore coherent length scales (km) for cross-shore (u) and alongshore (v) currents and temperature (T) from moored current meter arrays deployed between Del Mar and San Clemente, CA in 1980 and 1983 [2,4]. Summer observations are from the 1980 experiment; spring and winter from the 1983 experiment. There were no cross-shore sites in 1980. Table reproduced from Lentz [2], Table 6.

In general, the alongshore coherent lengths are longer than cross-shore lengths, and low frequency signals are much more highly correlated over distance than intermediate frequency signals. Signals with frequencies higher than the intermediate band shown here were uncorrelated at the shortest length scales considered in these experiments. These scales can provide guidance as to the possible spatial extent of signals observed at the mooring site.

2.2 Meteorology

Hourly averaged time series of all of the meteorological variables are shown in figures 2.18 through 2.21. Precipitation data is not shown because no precipitation was observed during the experiment. Conditions were foggy and hazy for most of the experiment and this is reflected in the relative humidity data (figure 2.18). There is a very moderate warming trend in both air and sea surface temperature. As previously indicated the alongshore winds were marginally upwelling favorable, with a mean value over the entire experiment of -0.45 m/s. Wind and wave conditions were relatively calm throughout the experiment (figure 2.20).

Incoming longwave and shortwave radiation are shown in figure 2.21. The bottom panel of figure 2.21 shows the net heatflux (positive into the ocean), calculated using TOGA COARE formulations [1]. The net average flux over the entire period was 91 W/m^2. The calculated heatflux can be used in a 1-D upper ocean model [3] to hindcast the surface heating seen in the SST data (figure 2.22). While the overall warming trend is predictable, the model does not capture the full range of diurnal variability, particularly beyond a few days past the initialization. Also, because

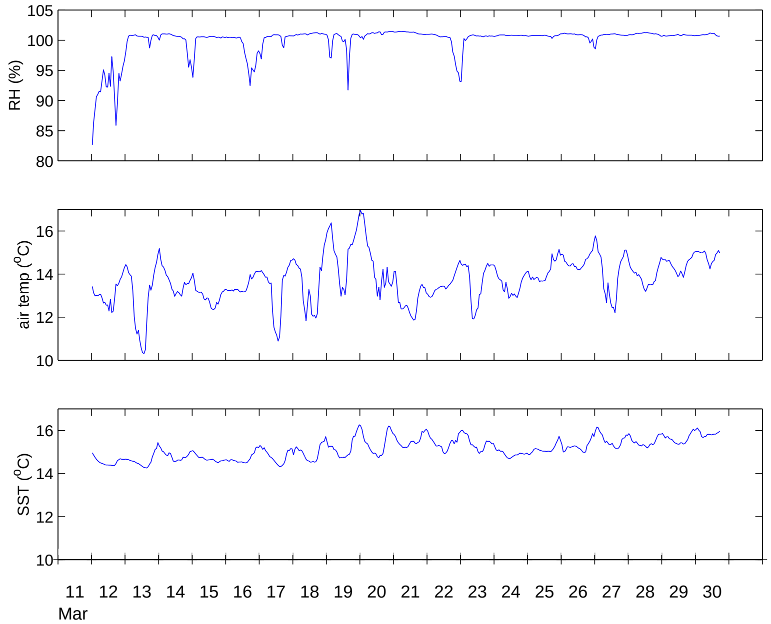

Figure 2.18: Hourly averaged relative humidity and air temperature from the ASIMET HRH module; sea surface temperature from the ASIMET SBE-37.

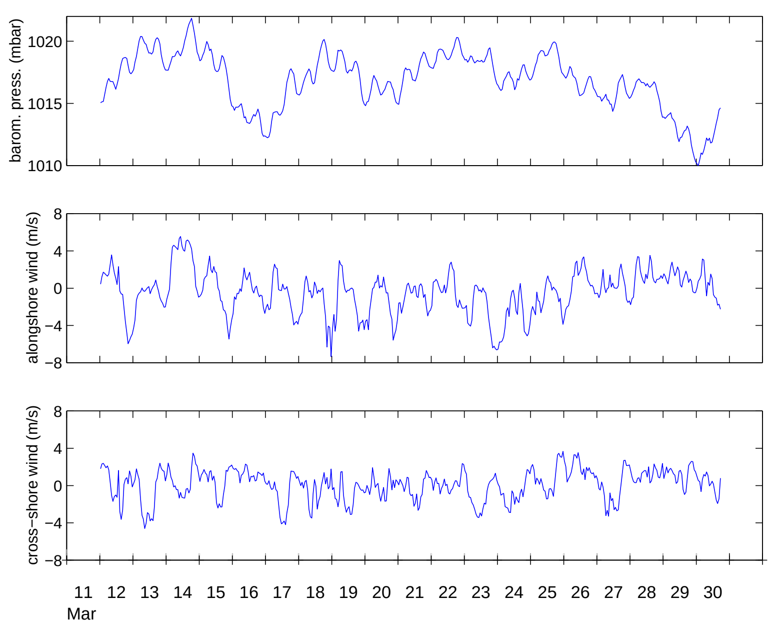

Figure 2.19: Hourly averaged barometric pressure and alongshore and cross-shore wind velocity, computed using a coastline orientation of 60° west of north. Alongshore wind is positive upcoast; cross-shore wind is positive oncoast.

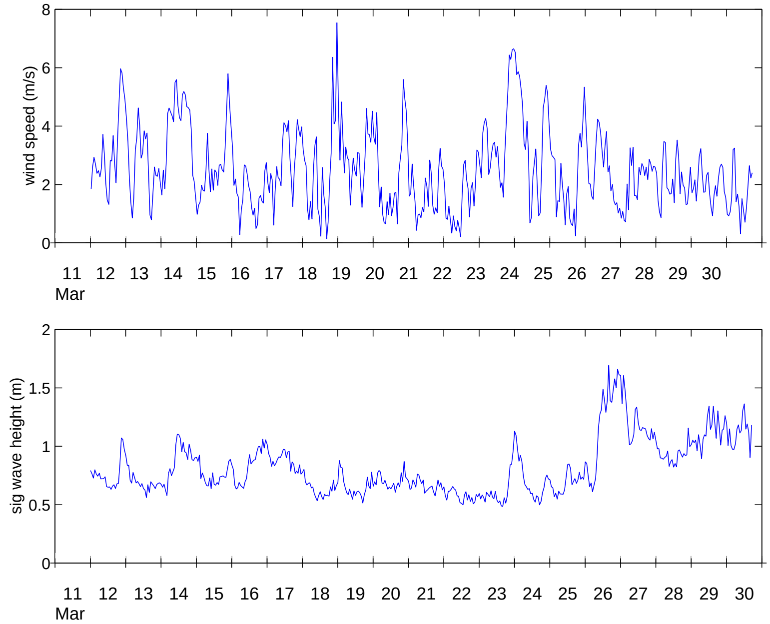

Figure 2.20: Hourly averaged wind speed (from the ASIMET system) and significant wave height from the tri-axial accelerometer on the surface buoy.

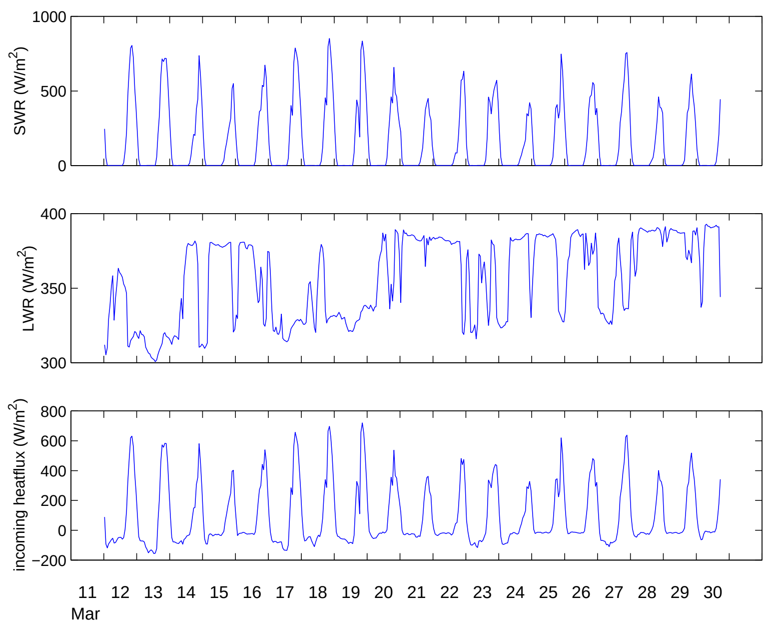

Figure 2.21: Hourly averaged shortwave and longwave radiation from the ASIMET SWR and LWR modules. Net incoming heatflux calculated using TOGA COARE formulae

.

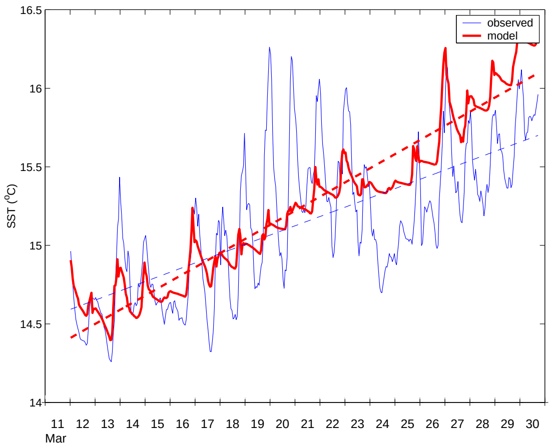

Figure 2.22: PWP modeled SST using hourly averaged air–sea fluxes and initialized by the pre-deployment CTD cast taken at the mooring site. The dashed lines show the linear trend in the observed and modeled time series.

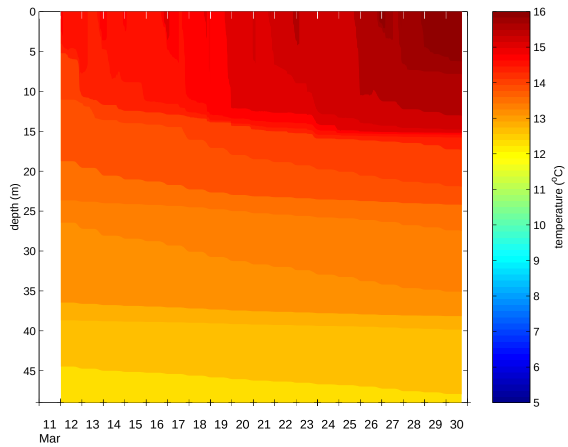

Figure 2.23: PWP modeled temperature contours.

of the marked semi-diurnal variability and the slow intrusion of cold, salty water along the bottom seen in figure 2.4, the model prediction is very poor over the full water column (figure 2.23).

2.3 Currents

Current data at the mooring site is available from the three Sontek Argonaut-MD single bin acoustic doppler current meters (two on the surface mooring, one on the subsurface mooring). For plotting, hourly averaged values of east, north, and up currents were computed. These hourly averaged values were then rotated into alongshore and cross-shore components, accounting for the 13.35° magnetic declination at the site. The coastline was assumed to be oriented along 120° – 300°. The averaged, rotated components are shown in figure 2.24.

As mentioned above, the large offshore flow at the surface may be indicative of upwelling. The most interesting signal in the current data, however, is the large, low frequency, downcoast pulse in the alongshore current that penetrates from near surface to at least 23 m. A possible explanation for the pulse is a coastal trapped wave.

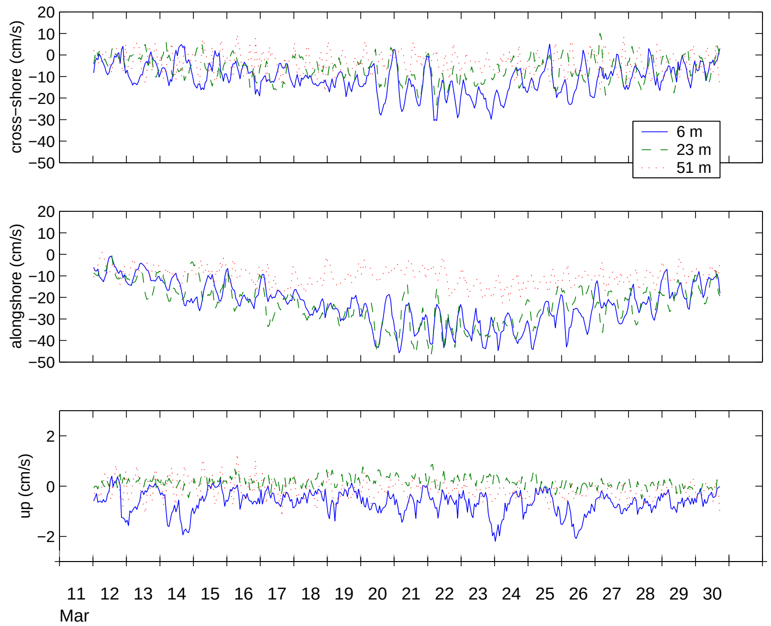

Figure 2.24: Hourly averaged cross-shore, alongshore, and up currents at 6 m, 23 m, and 51 m depths. Alongshore currents are positive upcoast, cross-shore currents are positive oncoast.

2.4 Optical properties

The a-Beta instruments on the mooring lines measure optical backscattering and transmission at 532 nm. The raw transmission values are used to calculate a diffuse attenuation coefficient, K_L, which is inversely proportional to visibility with a proportionality constant of approximately two (HOBI Labs, personal communication). Adding the pure water attenuation at 532 nm 0.045 m^{-1}, the formula for visibility is

$$V = \frac{2}{K_L + 0.045}. \tag{2.1}$$

These visibility values are plotted at the three depths in figure 2.25. Figure 2.26 shows visibility calculated from the near surface a-Beta along with surface visibility calculated from the SeaWiFS satellite imagery by researchers at the Naval Research Laboratory (Ocean Optics Code 7333, http://www7333.nrlssc.navy.mil/ocolor/Exercises/kernal_blitz2001/kbindex.html). The NRL visibility calculation uses data from the SeaWiFS 555 nm band (20 nm bandwidth).

From these results, visibility at the mooring site was substantially better than what operators were reporting for nearer shore, very shallow water (VSW) sites within the exercise. The visibility calculated from the near surface a-Beta is in general lower than that from the SeaWiFS 555 nm band imagery. The $2/K$ formulation for calculating visibility is an approximation based on the anecdotal experience of HOBI Labs researchers. It is not based on HOBI Labs more formally and rigorously

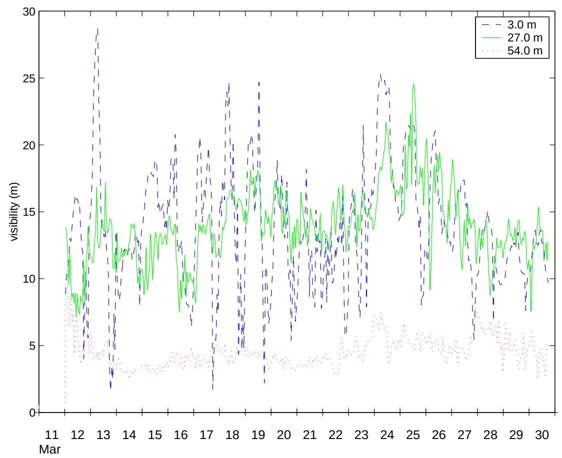

Figure 2.25: Visibility at the three a-Beta instruments using the $2/K$ formulation. Hourly K_L values were computed from the single ten second average raw transmission value returned via telemetry.

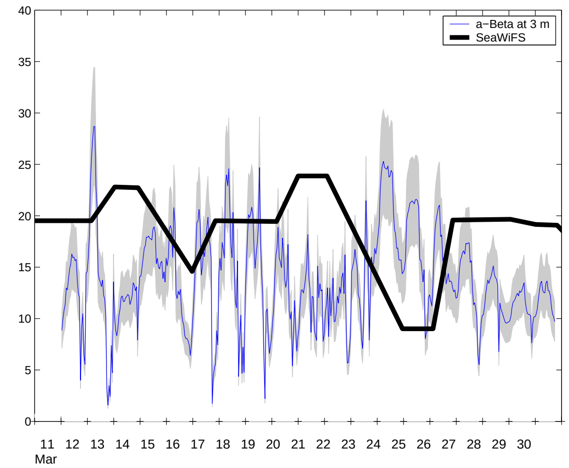

Figure 2.26: Near surface a-Beta and surface SeaWiFS visibility. The shaded grey area represents the ±20% error bars on the a-Beta value. Data for the SeaWiFS visibility was extracted by digitizing the bitmapped image available on the NRL website cited in the text.

developed DiVA (Distance Visibility Algorithm).

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[1] C.W. Fairall, E.F. Bradley, D.P. Rogers, J.B. Edson, and G.S Young. Bulk parameterization of air–sea fluxes for TOGA COARE. *Journal of Geophysical Research*, 101:3747–3764, 1996.

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[4] Clinton D. Winant. Longshore coherence of currents on the Southern California shelf during the summer. *Journal of Physical Oceanography*, 13(1):54–65, 1983.

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16. Abstract (Limit: 200 words)
In this report we describe a compact, easily deployed, moored system for oceanographic and meteorological observations in the coastal ocean. The system consists of a surface and subsurface mooring pair deployed adjacent to one another. Compared to a single catenary surface mooring, this arrangement allows the entire water column to be instrumented. All of the instruments in the system log high resolution time series data. Additionally, the mooring line instruments periodically report averaged data to the buoys via inductive modems. On the subsurface mooring, this averaged data is sent to the surface buoy using an acoustic modem. Inductively coupled mooring line instrumentation includes conductivity, temperature, and pressure sensors, acoustic current meters, and optical backscattering and absorption sensors. In addition to mooring line instruments, the surface buoy collects averaged data from meteorological sensors, including wind speed and direction, barometric pressure, relative humidity, air temperature, precipitation, longwave and shortwave radiation, sea surface temperature and conductivity, and wave height and period. Data from both mooring lines and from the surface meteorological sensors is telemetered to shore via line-of-sight radio and satellite. The entire system, including buoys, moorings, instruments, launch and recovery gear, telemetry receive, and data processing facilities can be packed into a single 20 foot shipping container. The system was successfully deployed to provide environmental monitoring for Kernel Blitz 2001, a US Navy fleet exercise off southern California. Results from the deployment are presented.

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